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THESIS

NPS CUBESAT LAUNCHER PROGRAM MANAGEMENT

by

Christina M. Hicks

September 2009

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The purpose of this thesis is to document my activities related to managing the design, analysis, construction, testing, and integration of a qualification and, possibly, a flight article in support of the NPS CubeSat Launcher (NPSCuL) project. This thesis will describe the process, experience, and results of managing the NPSCuL program, including the program budget and schedule in support of a flight opportunity as early as August 2010. NPSCuL is designed to utilize excess capacity on U.S. launch vehicles to place a significant volume of CubeSats into orbit in a single launch. The NPSCuL will be a secondary payload attached to the launch vehicle via the EELV Secondary Payload Adapter (ESPA) or other compatible launch vehicle structures. The NPSCuL-Lite, a modified version of the NPSCuL, integrates eight Poly-Picosatellite Orbital Deployers (P-PODs) with a deployment sequencer in a simple structure. NPSCuL-Lite will be able to accommodate up to twenty-four units of CubeSat volume. The goal of the NPSCuL project is to improve CubeSat access to space, advance U.S. space technology, and ensure that the next generation of U.S. space professionals will remain on the cutting edge of very small satellite development.

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NPS CUBESAT LAUNCHER PROGRAM MANAGEMENT

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Submitted in partial fulfillment of the
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ABSTRACT

The purpose of this thesis is to document my activities related to managing the design, analysis, construction, testing, and integration of a qualification and, possibly, a flight article in support of the NPS CubeSat Launcher (NPSCuL) project. This thesis will describe the process, experience, and results of managing the NPSCuL program, including the program budget and schedule in support of a flight opportunity as early as August 2010. NPSCuL is designed to utilize excess capacity on U.S. launch vehicles to place a significant volume of CubeSats into orbit in a single launch. The NPSCuL will be a secondary payload attached to the launch vehicle via the EELV Secondary Payload Adapter (ESPA) or other compatible launch vehicle structures. The NPSCuL-Lite, a modified version of the NPSCuL, integrates eight Poly-Picosatellite Orbital Deployers (P-PODs) with a deployment sequencer in a simple structure. NPSCuL-Lite will be able to accommodate up to twenty-four units of CubeSat volume. The goal of the NPSCuL project is to improve CubeSat access to space, advance U.S. space technology, and ensure that the next generation of U.S. space professionals will remain on the cutting edge of very small satellite development.

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I. INTRODUCTION AND BACKGROUND

A. CUBESATS AND P-PODS

The CubeSat Project began in 1999 as a collaboration between California Polytechnic State University (Cal Poly) and Stanford University, to provide a standard design of picosatellites that would reduce cost and development time, increase accessibility to space, and sustain frequent launches [1]. The CubeSat design is a 10 cm cube weighing no more than 1 kg, commonly referred to as a “1U” (Figure 1). CubeSats can currently be in any configuration up to a “3U” or 10 cm x 10 cm x 30 cm as shown in Figure 2.

Figure 1. 1U CubeSat Form Factor

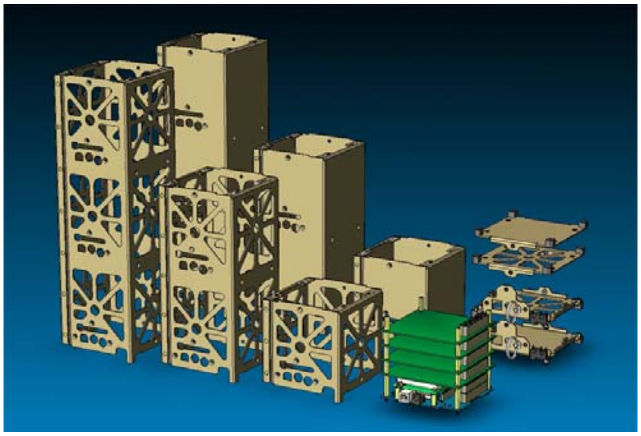

Figure 2. CubeSat Configurations

In order to accommodate launching CubeSats, Cal Poly designed and developed the Poly Picosatellite Orbital Deployer (P-POD), a standardized CubeSat deployment system [2]. The P-POD is an aluminum box with a door and spring mechanism that can accommodate up to three 1U CubeSats or a single 3U CubeSat. Upon receipt of a deployment signal from the launch vehicle, a non-explosive actuator (NEA) releases the door and allows the CubeSats to slide along a series of rails and eject from the P-POD.

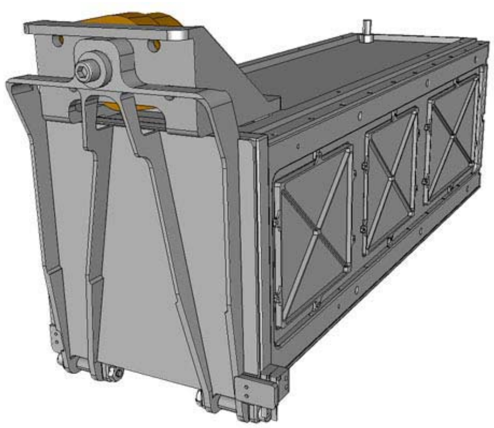

Figure 3. P-POD (From [1])

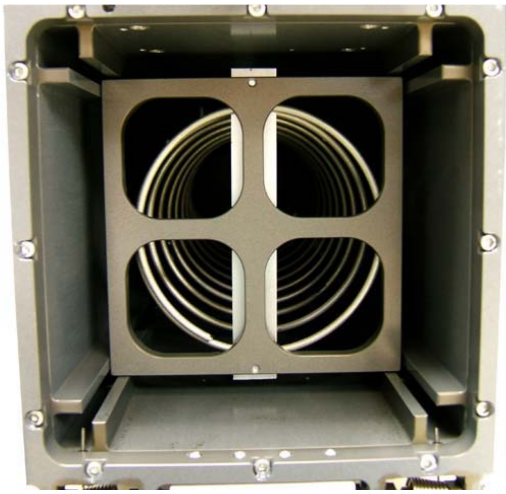

Figure 4. P-POD Cross Section (From [1])

P-PODS are secondary payloads mounted on launch vehicles. Cal Poly typically acts as launch coordinator between the CubeSat developers and the launch vehicle provider. In order to provide CubeSat developers with launch opportunities at a reasonable cost, P-PODS are typically secondary payloads on foreign launch vehicles, to date most of which have been Russian. Out of 44 total CubeSats launched, 30 launched from Russia, six launched from India, and one launched from Japan. Prior to May of 2009, only one CubeSat had been successfully launched from the United States; NASA's GeneSat-1 launched on a Minotaur-1 out of Wallops Island, VA in December 2006. As of the date of this thesis, only four CubeSats have been launched from the U.S. this year: PharmaSat, CP6, AeroCube-3, HawkSat-1, also on a Minotaur-I out of Wallops Island. This is despite the fact that every year there are thousands of kilograms of excess payload capacity on U.S. launchers. Figure 5 shows a sample of the mission margins on United Launch Alliance launch vehicles, Atlas V and Delta IV, for the years 2007–2010. In 2008, there was over 8000 kg of unused excess payload capacity [3].

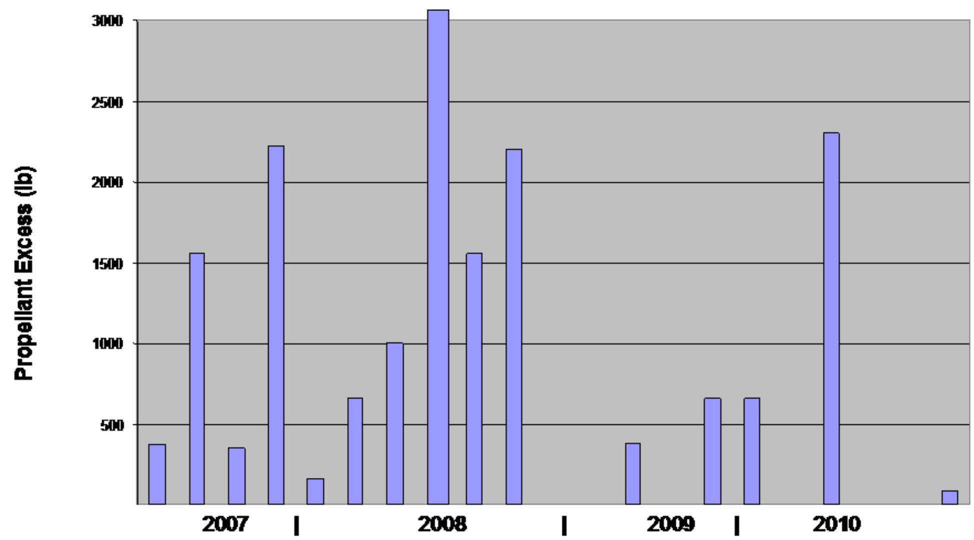

Figure 5. Sample of Mission Margins (From [3])

Despite limited launch availability, the number of CubeSat developers continues to grow. According to the CubeSat participant list [4], the number of CubeSat developers is well over 100 including universities, high schools, private firms and government agencies. Compared to other satellites, CubeSats are relatively inexpensive and quick to develop and build, making them ideal for educational purposes. In addition, industry and government agencies are finding CubeSats to be useful due to advances in miniaturizing technology and an environment of tight budget constraints. The NPS CubeSat Launcher (NPSCuL) evolved as a means to leverage the affordable capabilities of CubeSats and utilize some of the thousands of kilograms of excess payload capacity on U.S. military and government Evolved Expendable Launch Vehicles (EELVs) to provide high capacity CubeSat access to space from the United States.

B. THE LAUNCHER

The original design of the NPSCuL as depicted in the thesis, “Structural Design of a NPS CubeSat Launcher” [5] accommodated up to fifty 1U Cubesats. This design was modified to a more compact and lightweight version, the NPSCuL-Lite, in order to be compatible with a launch opportunity on the Atlas V

Aft Bulkhead Carrier (ABC) as described in the thesis, “NPS CubeSat Launcher (NPSCuL)” [6]. The ABC is a system developed by the United Launch Alliance (ULA) to support and deploy a single secondary payload (SP) from the aft end of the Centaur or upper stage [7].

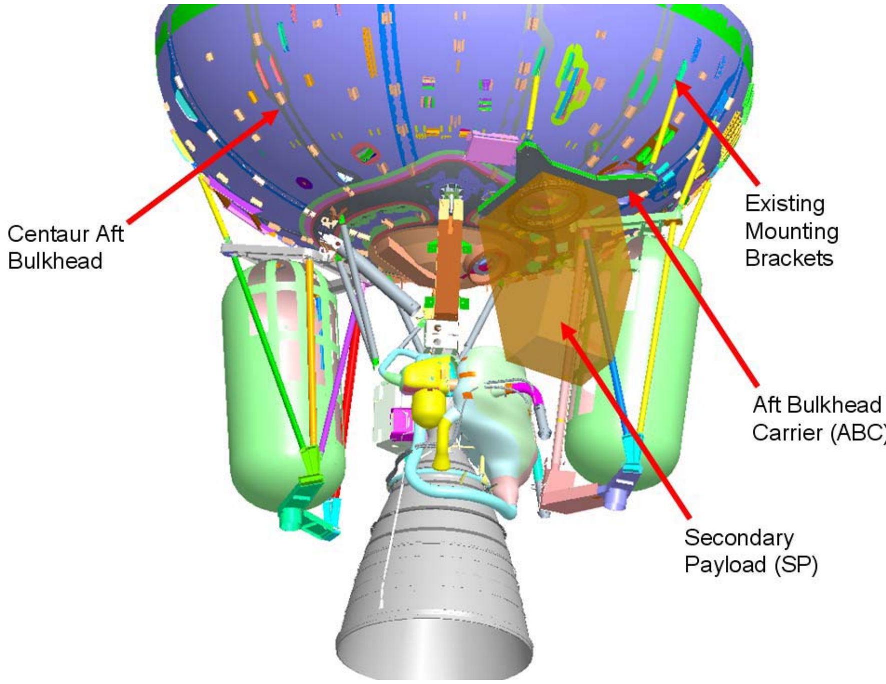

Figure 6. Atlas V ABC with SP Installation (From [7])

The National Reconnaissance Office (NRO) CubeSat Program Office, or QbX, is promoting the flight of ADaMSat, the Advanced Systems and Technology (AS&T) Development and Maturation Satellite on NRO L-41, an Atlas V currently scheduled to launch no earlier than August 2010 from Vandenberg AFB. ADaMSat comprises NPSCuL-Lite, the ADaMSat Sequencer Box (ASB), and the P-PODs and CubeSats.

1. Design

To effectively develop the NPSCuL-Lite in an educational environment with a success-oriented schedule, the design has been kept simple. Existing standards and interfaces have been utilized such as the EELV Secondary

Payload Adapter (ESPA) [8] and Cal Poly's P-POD, which has flight heritage. The NPSCuL-Lite itself is just a box-like structure of Aluminum 7075 that incorporates eight P-PODS in a pinwheel configuration in the interior of the structure, accommodating up to twenty-four 1U CubeSats.

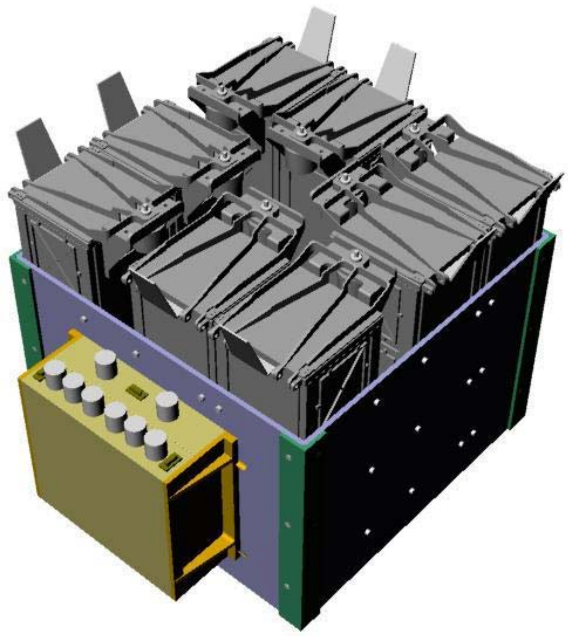

Figure 7. NPSCuL-Lite Integrated with P-PODs and Sequencer

The NPSCuL-Lite structure with the adapter ring is approximately 15 inches high and 19 inches in length and width. The four side walls are 0.25 inches thick, and the base plate is 0.50 inches thick. The brackets on each corner are 3/16 inches thick. The assembled structure weighs almost 42 lbs including fasteners and adapter ring. Fully loaded with P-PODs, CubeSats, and a sequencer, the NPSCuL-Lite weighs nearly 170 lbs.

The dimensions of the integrated NPSCuL-Lite are shown in Figure 8.

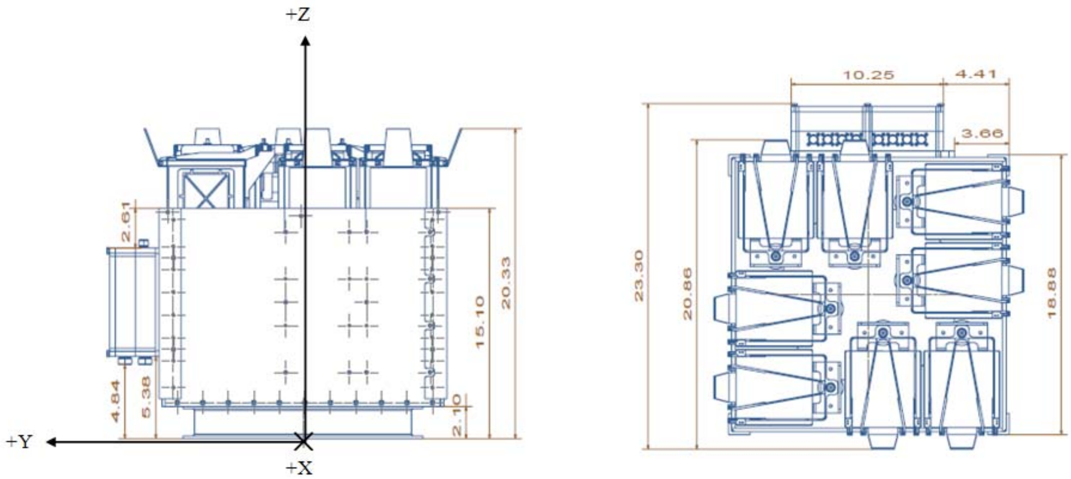

Figure 8. NPSCuL-Lite with Dimensions and Coordinates

a. Mass Properties

The NPSCuL-Lite mass budget is summarized in Table 1 below. Each 3U P-POD weighs approximately 2.5 kg. The P-POD Mark III ICD [2, Table 1, p. 9] lists the mass as 2.25 kg for an empty P-POD, but this does not include harnesses and door stops. A CubeSat mass of 1.5 kg per 1U is a worst case scenario in the event that a 3U CubeSat delivered for integration is heavier than the standard [1, p. 5], recently increased from 1kg per U to 1.33 kg per U. The sequencer mass of 3 kg is an estimate provided by Design_Net Engineering based on the Multiple Interface Payload Subsystem (MIPS) specification. Recently, the sequencer vendor was changed to Ecliptic Enterprises. In order to minimize design impacts, the sequencer to be built by Ecliptic Enterprises is not to exceed this specification. The weight of the assembly hardware and structure was determined using actual hardware for the NPSCuL-001. The mass budget for NPSCuL-Lite shown below does not take into account the adapter ring, which is discussed in the next section; therefore, the mass margin is calculated based on a maximum SP mass of 170 lbs.

	Weight (kg)	Weight (lbs)	Num	Total (kg)	Total (lbs)
3U P-PODs	3	6	8	20	44
CubeSats	2	3	24	36	79
Sequencer	3	7	1	3	7
Assembly Hardware	1	2	1	1	2
Structure	17	37	1	17	37
Total				**76**	**168**
Mass Margin				1	2
% Mass Margin				1%	

Table 1. NPSCuL-Lite Mass Budget Summary

b. Adapter Ring

Attached on the bottom plate is an adapter ring that is compatible with the EELV Secondary Payload Adapter (ESPA) fifteen-inch circular bolt hole pattern.

Figure 9. ESPA with 15” Adapter Ring

The adapter ring was designed to simulate the dimensions of the Lightband. The Lightband, a separation system developed and built by Planetary Systems Corporation, was the baseline separation system for the ABC providing a standardized SP interface that is compatible with the ESPA interface. ULA initially allocated 5.6 lbs for the separation system and 24 fasteners. Since the NPSCuL-Lite is a non-separating payload, the 5.6 lbs was reallocated to the SP mass to include the 24 fasteners, which mount the SP to the ABC [9]. The adapter ring is 2.1 inches tall and weighs 3.4 lbs. The mass margin depicted in Table 2 is calculated using a maximum SP mass of 175.6 lbs.

	Weight (kg)	Weight (lbs)	Num	Total (kg)	Total (lbs)
3U P-PODs	3	6	8	20	44
CubeSats	2	3	24	36	79
Sequencer	3	7	1	3	7
Assembly Hardware	1	2	1	1	2
Adapter Ring	2	3	1	2	3
Structure	17	37	1	17	37
Total				**78**	**172**
Mass Margin				2	4
% Mass Margin				2%	

Table 2. NPSCuL-Lite Mass Budget Summary Including Adapter Ring

c. Compatibility

The NPSCuL-Lite dimensions and mass are compatible with both the ESPA and the ABC secondary payload volumes. The secondary payload volume is 24” x 24” x 38” for the standard ESPA envelope [8]. The spacecraft mass and cg requirements are per Figure 10. The integrated NPSCuL-Lite is approximately 170 lbs with a height of less than 21 inches, so it falls within the allowable ESPA mass envelope regardless of the cg location.

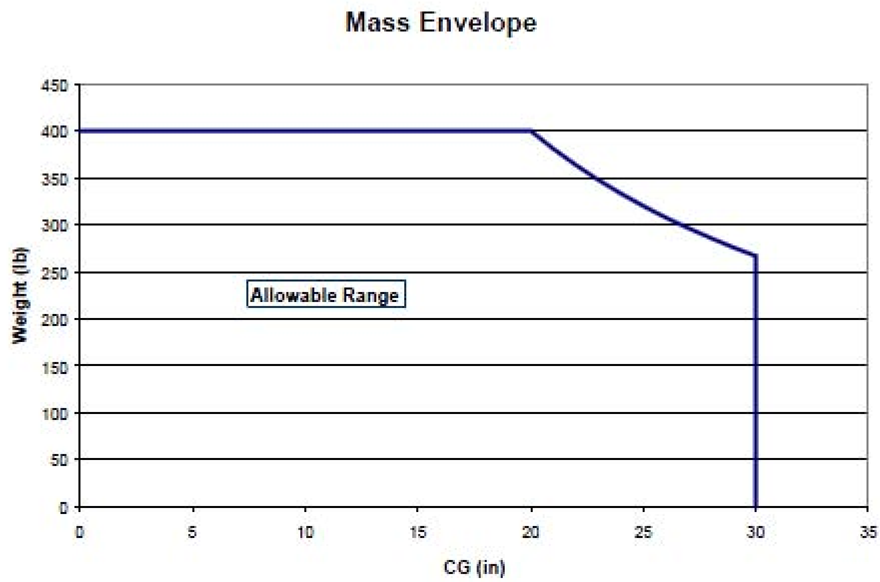

Figure 10. Allowable Spacecraft Mass and Center of Gravity on ESPA (From [10])

The ABC static envelope was defined with the NPSCuL-Lite spacecraft in mind, hence the additional volume capability over the separating payload volume to accommodate the externally mounted sequencer and P-POD door stops. The resulting non-separating secondary payload volume for the ABC is shown in Figure 11. In addition, the ABC structural design section of the Atlas V ABC PDR [10] stated, "If required, small, localized excursions may be allowable." The mass and cg requirements are listed in Table 3 and do not include the separation system or adapter ring for a non-separating SP. Table 4 is the allowable ADAMSAT mass properties including the adapter ring from the ADaMSat to Atlas V/ABC ICD.

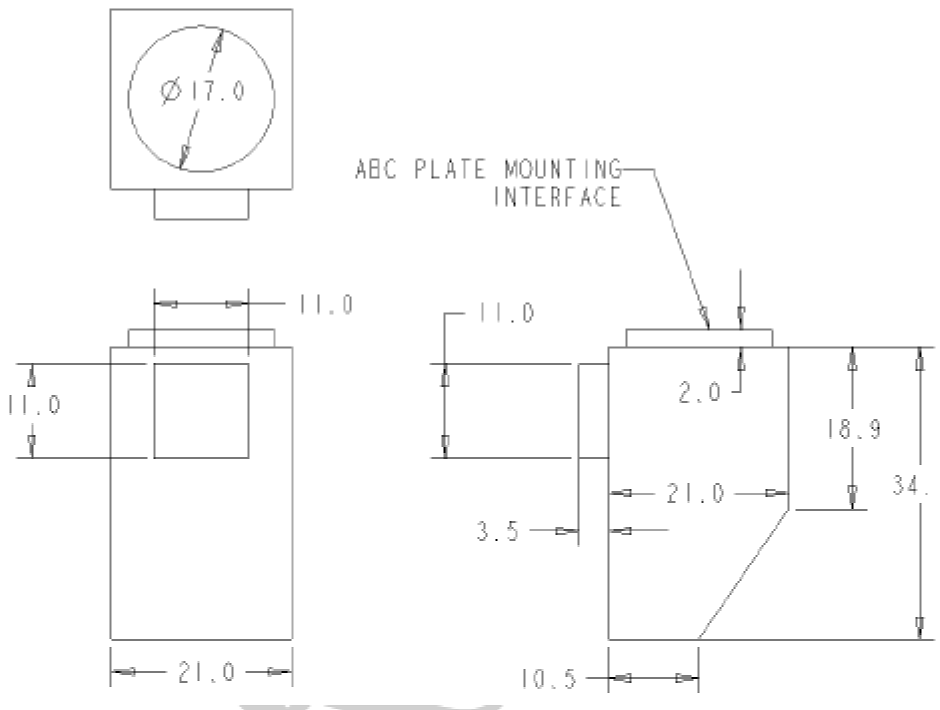

Figure 11. ABC Static Envelope Definition (in inches) (From [9])

Pre-SP Separation Maneuver	SP Mass, kg (lb)	SP Z cg Location, mm (in.)	SP X & Y cg Offsets, mm (in.)
3-Axis Stabilized Attitude Hold	65.8 +\- 11.3 (145 +\- 25)	243.84 +\- 190.5 (9.6 +\- 7.5)	+\- 12 (+\- 0.5)

Table 3. Design Range of SP Mass Properties for ABC (From [7])

Mass (lbs)	[165 +\- 10]*
Center of Gravity (in)	
X	[0.00 +\- 2.0]
Y	[0.00 +\- 2.0]
Z	[17.45 +\- 2.0]

*Includes Adapter Ring

Table 4. ADAMSAT Mass Properties (From [9])

d. Sequencer

The sequencer acts as an electrical interface between the launch vehicle and the NPSCuL and controls the sequence of P-POD deployment and the routing of telemetry data. The sequencer is powered up by the launch vehicle and accepts the command signals (primary and redundant) that indicate it is time to deploy the P-PODs. The sequencer contains the control electronics that activate the P-POD non-explosive actuators (NEAs) in a predetermined deployment sequence. Each P-POD has a door switch that may be continuously monitored by the launch vehicle, via the sequencer, and indicates whether the door is closed or not.

Although some work was done at NPS on a sequencer, in order to meet required hardware delivery deadlines, it was determined that the most efficient way forward was to procure a sequencer commercially. This was a source of significant risk to the program, since funding for a commercial sequencer was not available until recently. The NPSCuL team had to build and integrate a mass model for qualification testing based on the Design_Net Engineering Multiple Interface Payload Subsystem (MIPS) product specification [11] without a guarantee that it would be the actual flight sequencer.

For the first flight of the NPSCuL-Lite, the sequencer will be a commercial product designed and built by Ecliptic Enterprises with a back up potentially available from Design_Net Engineering. This sequencer is referred to as the ADaMSat Sequencer Box or ASB.

e. Mass Models

The NPSCuL qualification unit consists of a flight-like structure with aluminum mass models of the P-PODs and sequencer. The use of mass models keeps the cost of the project down; although it does decrease the fidelity of the testing as the mass models cannot completely duplicate the characteristics of the P-PODs. The mass models are made of Aluminum 6061 and mimic the mass and center of gravity of the actual P-PODs and sequencer. The P-POD mass model (P2M2) weight is approximately 7.0 kg and is based on a P-POD weight of 2.5 kg and a maximum 3U CubeSat weight of 4.5 kg. The sequencer mass model (SM2) weighs approximately 3.4 kg or 25 percent more than the projected mass of the actual unit. [Note: the SM2 mass properties were based on the Design_Net MIPS specification.]

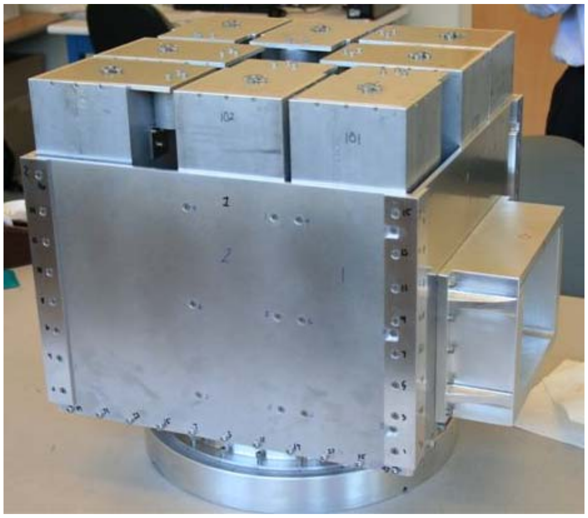

Figure 12. NPSCuL-Lite Integrated with version 1 P-POD and Sequencer Mass Models

These mass model designs are a bit heavier than expected for most of the flight units and place more load on the NPSCuL structure in order to increase the margin of safety. The additional weight on the structure also ensures that the structure can handle the weight of the cables and harnessing when they are incorporated.

The first version of the P2M2s were based on a Cal Poly design and went through a test program in order to qualify them. Based on the results of the first qualification test, the P2M2s were redesigned in order to make them simpler and minimize the requirement for any fasteners. The rationale behind this decision is discussed in Section IV. The resulting P2M2v2s are each made of a single piece of Aluminum 6065 but have been machined to match the mass and cg characteristics of an actual P-POD. Rails were also added to make the P2M2s more like the P-PODs. The updated mass models are shown in Figure 14.

Figure 13. Side by Side Comparison of P2M2 Versions 1 and 2

2. Environmental Test Parameters

The testing of the NPSCuL qualification unit includes a sine sweep of 15-500 Hz to characterize the structure before and between each test, a sine burst of five pulses at 25 Hz with a 12.4 g peak, and a random vibration to four times (+6dB; 15.2 g) the expected launch loads for three minutes on each axis [12]. Due to the location of the ABC on the aft end of the upper stage, the qualification vibration loads are more severe than those normally seen on an ESPA. This means that qualifying the NPSCuL-Lite for the ABC should also qualify it per ESPA requirements. The chart below shows the maximum predicted and qualification (+6 dB) random vibration acceleration spectral density (ASD) for the ABC in pink and for the NASA general environment verification qualification specification qualification for the ESPA in green.

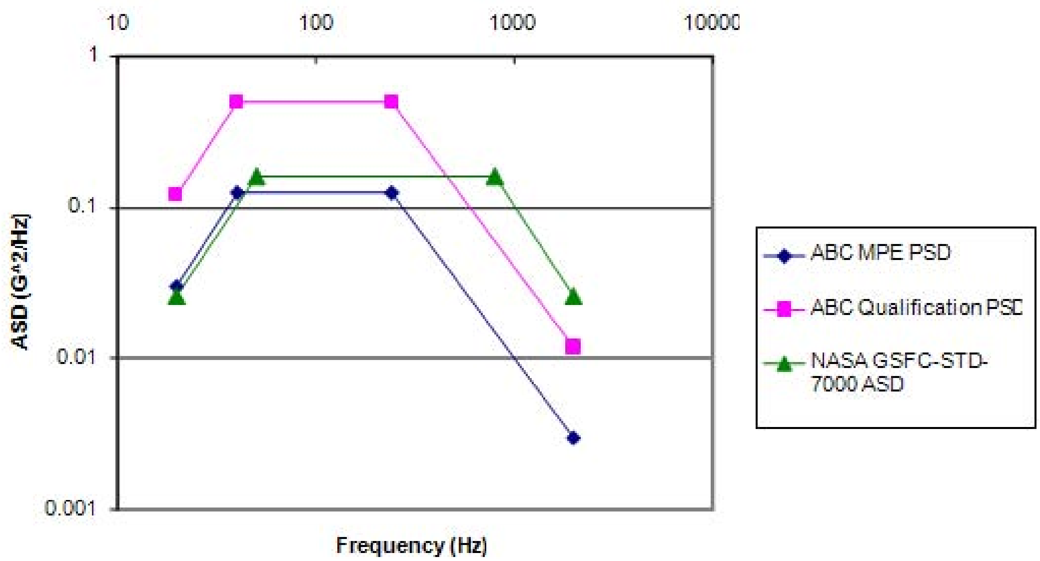

Figure 14. ABC Vibration Requirements vs NASA General Environment Verification Specification (From [12])

3. Integration

Although NPSCuL-Lite is scheduled for launch in August 2010, one of the goals of the program is to be routinely manifested on EELV launches. In support of this goal, a Payload Planner's Guide was developed as part of the thesis, "NPS CubeSat Launcher (NPSCuL)" [6] in order to identify a payload integration process for manifesting and routinely launching NPSCuL-Lite. It is conceivable that NPS could manage part of the payload selection process, in conjunction with the Department of Defense (DoD) Space Test Program (STP), the primary provider of spaceflight for DoD space experiments. The process would involve procuring and integrating Cal Poly's P-PODS with the NPSCuL-Lite. NPS would coordinate with the STP (or any other NPSCuL-Lite compatible flight providers) for launch opportunities. Once a launch provider has been identified and all STP sponsored CubeSats manifested, any excess capacity will be identified. Candidate CubeSats from universities and industry would be nominated for launch on NPSCuL-Lite and their selection coordinated with STP. In this way, U.S. Government CubeSats would have first priority for launch on NPSCL, but any excess capacity could be utilized for potential educational and innovation outreach opportunities. Cal Poly would be the point of contact (POC) for non-government CubeSat providers as well as ensuring that all CubeSats to be launched on NPSCuL-Lite have met the test and verification requirements as standardized by the CubeSat community and the P-POD launcher. An integrating contractor would be responsible for ensuring that all components including the NPSCuL-Lite structure, P-PODs, CubeSats, and sequencer meet the launch provider's test, verification and safety requirements including the Mission System Prelaunch Safety Package (MSPSP). The integrating contractor would also be responsible for final satellite mechanical and electrical integrations and preparations prior to delivery to the launch provider.

For the NRO L-41 launch, the integrating contractor or Launch Systems Integration Manager (LSIM) is an Aerospace Corporation contractor in the QbX office in Albuquerque, NM. The ADaMSat poses a unique challenge to the LSIM as there are several organizations delivering key components of the satellite including NPS, Cal Poly, and Ecliptic Enterprises for the ADaMSat structure, P-PODs, and sequencer. The payload currently includes CubeSats ranging from 1U to 3U from Space and Missile Defense Command (SMDC), the National Science Foundation (NSF), Los Alamos National Laboratory (LANL), and NASA KSC and Ames. The organization chart depicting the organizations responsible for ABC and ADaMSat is shown in Figure 15. The solid lines denote where contractual relationships exist; whereas, the dashed lines denote cross-coordination and lines of communication between organizations.

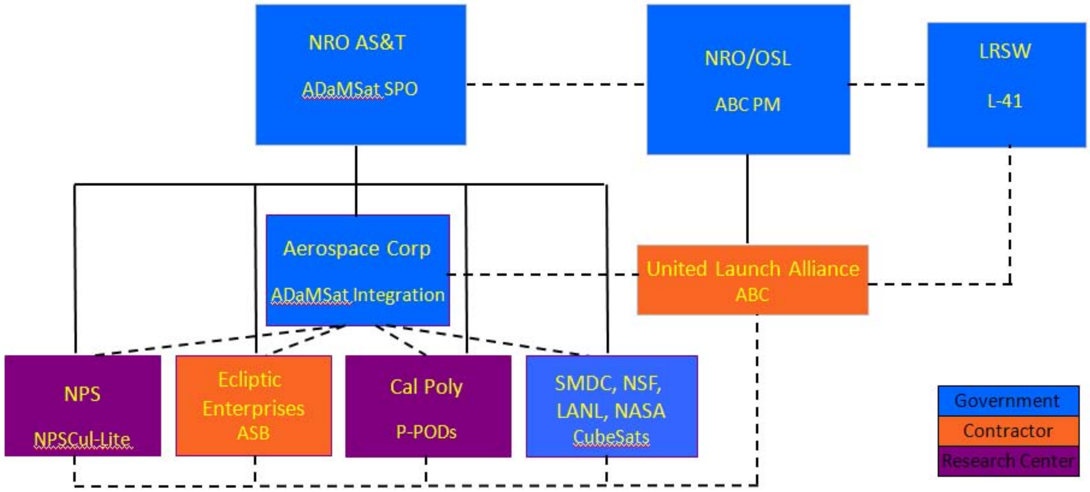

Figure 15. ABC/ADaMSat Responsible Organizations (From [13])

The LSIM acts as the primary interface between the project item providers (i.e., NPS, Ecliptic, Cal Poly, and the CubeSat developers) and the launch provider via the Systems Program Office (SPO), NRO Advanced Systems and Technology (AS&T). The LSIM is responsible for generating the ADaMSat ICD as well as gathering and organizing all test, verification, and safety documentation from each organization and providing it to the launch provider, United Launch Alliance (ULA). One challenge facing ADaMSat is that the LSIM does not have facilities adequate to support mechanical and electrical integration of the satellite; therefore, they must coordinate with other organizations, possibly the Air Force Research Lab (AFRL), Naval Postgraduate School (NPS), Cal Poly, and SRI International in order to conduct final integration.

In addition to the organizations contributing components of the ADaMSat, there are many other organizations involved in the integration of the ADaMSat to the NRO L-41 launch. United Launch Alliance (ULA) is building the ABC. The ABC Program Manager in the Office of Space Launch (OSL) is funding ULA for the development of the ABC. The Launch and Range Systems Wing (LRSW) (formerly the EELV Program Office) and the Program Officer for the NRO L-41 primary payload are both providing oversight of the ABC program to ensure no risk is added to the primary mission. In addition, LRSW and OSL have responsibility for flight certification of the ABC and ADaMSat, respectively.

II. BUDGET

A. ROLES AND RESPONSIBILITIES

The principal investigator (PI) is the faculty member leading the sponsored research effort and has ultimate responsibility for the conduct of that funded research [14]. For the purpose of this thesis, the program manager is the student who accepts a leading role and a lot of the responsibility for the conduct of the sponsored research, all as part of that student's thesis project. The PM is responsible for the technical and fiscal management of a sponsored project, assurance that funds are spent in accord with appropriation law and applicable policy and budget agreed to by the sponsor, and assuring quality of the project deliverable. Integral to this relationship is the Assignation form authorizing the PM to initiate expenditures in support of the project and make modifications to the approved expenditure control page. This means that the PI delegates the authority to spend project funds to the PM, while still retaining responsibility for the funds through the attestation process. The Assignation of Responsibilities form for the FY09 CSEWI funding is in Appendix A.

Although a draft budget typically exists as part of a successful proposal, the PM becomes responsible for maintaining and updating the budget, as is frequently required by the nature of doing research. Additionally, the PM is authorized to initiate purchases by sending completed purchase requests to the SPFA with a courtesy copy sent to the PI. In this way, the PI has cognizance of the way the funds are being spent in addition to routine budget updates from the PM. A template of the purchase request form may be found at the NPS Research and Sponsored Programs Administration website:

http://www.nps.edu/research/rspa.html#Forms.

The Sponsored Program Financial Analyst (SPFA) is the individual providing financial support to the PI/PM [14]. Upon receipt of each purchase request, the SPFA verifies the project account has adequate funds for the expenditure and verifies that the expenditure directly supports project activities as outlined in the statement of work (SOW). The SPFA then assigns each purchase request a requisition number and forwards it to a Purchasing Agent who actually places the order using a government commercial purchase card. The SPFA also tracks obligations and transactions via the DMAS budget pages. The Distributed Management Accounting System (DMAS) is a memorandum accounting system. Since the PM does not have access to DMAS, the SPFA provides financial status reports or copies of the DMAS budget pages for the PM to reconcile the locally generated budget. Of note is that all DMAS reports are unofficial unless reconciled with the Departmental Online Reporting System (DORS).

B. FUNDING

1. QbX

When the launch opportunity for NPSCuL-Lite was identified on NRO L-41, the program had exhausted almost all of the $20,000 of FY2008 funds provided by the California Space Authority under a grant from the California Space Education and Workforce Institute (CSEWI). In order for the program to continue past the CSEWI period of performance and work towards development of flight hardware, more funding was required. The QbX office under NRO Advanced Systems and Technology (AS&T) provided NPS with $39,000 of FY2009 funds to continue the program in support of ADaMSat and the L41 launch.

A proposal, which includes the standard NPS signature page, statement of work (SOW) and supporting budget, was generated for the QbX funds. The SOW includes the scope of work to be performed, description of the tasks to be performed, deliverables, period and place of performance, schedule of deliverables, points of contact, required travel, and a cost estimate [15]. The budget proposal delineates the complete cost of the project and identifies the amount required from the sponsor for the team to complete the activities in the proposed SOW [14]. Upon approval the funds were transferred via military interdepartmental purchase request (MIPR), which is a request for materials or services, either on a reimbursable or direct citation basis [16].

	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	August	Sept	Yearly Total	Target (Set at beginning of year)
Labor	0.00	868.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	868.87	14355.51
Contracts/Services	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	150.00	0.00	0.00	250.00	0.00
Travel	0.00	1,738.41	1,068.40	0.00	977.15	0.00	2,274.68	0.00	0.00	0.00	2,175.14	0.00	8,233.78	3,000.00
Students	0.00	1738.41	1068.40	0.00	977.15	0.00	2,274.68	0.00	0.00	0.00	2,175.14	0.00	8,233.78	0.00
Equipment & Supplies	0.00	1,564.77	1,822.69	0.00	6,913.24	4,816.30	75.94	4,615.34	334.90	0.00	0.00	0.00	20,143.18	12,282.00
a) E&S less than $15k	0.00	1,564.77	1,822.69	0.00	6,913.24	1,966.30	0.00	0.00	0.00	0.00	0.00	0.00	12,267.00	0.00
Structure (Aluminum)	0.00	0.00	0.00	0.00	2,980.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,980.97	0.00
P-Pod Mass Models	0.00	1,564.77	1,822.69	0.00	379.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3,766.46	0.00
Sequencer Materials	0.00	0.00	0.00	0.00	361.16	1,051.30	0.00	0.00	0.00	0.00	0.00	0.00	1,412.46	0.00
Structure Fasteners	0.00	0.00	0.00	0.00	3,192.11	915.00	0.00	0.00	0.00	0.00	0.00	0.00	4,107.11	0.00
b) E&S greater than $15k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
c) Software and support	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
d) Miscellaneous	0.00	0.00	0.00	0.00	0.00	0.00	75.94	0.00	334.90		0.00	0.00	410.84	0.00
e) Manufacturing	0.00	0.00	0.00	0.00	0.00	2,850.00	0.00	0.00	0.00	0.00	0.00	0.00	2,850.00	0.00
f) Testing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,615.34	0.00	0.00	0.00	0.00	4,615.34	0.00
Vibration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,615.34	0.00	0.00	0.00	0.00	4,615.34	0.00
TVAC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indirect Cost	0.00	1,317.95	913.30	0.00	2,492.57	1,521.47	774.15	1,457.99	105.79	47.39	687.13	0.00	9,317.73	9,362.49
Total Expenses	0.00	5,490.00	3,804.39	0.00	10,382.96	6,337.77	3,124.77	6,073.33	440.69	47.39	2,862.27	0.00	38,813.56	39,000.00
Actual Cumulative Expenses	0.00	5,490.00	9,294.39	9,294.39	19,677.35	26,015.12	29,139.89	35,213.22	35,653.91	35,701.30	38,563.56	38,563.56		

Table 5. Budget for QbX FY2009 Funds

At the beginning of the fiscal year, the estimated costs for each category were as shown in the Table 6.

Estimated Costs	$ (dollars)
Labor	14355.51
Contracts/Services	0.00
Travel	3,000.00
Equipment/Supplies	12,282.00
Indirect	9,362.49

Table 6. Estimated Costs in $ for QbX FY2009 Funds

Initially, labor was estimated to be the greatest expense in order to pay for the time of the Principal Investigator. Equipment and Supplies was expected to be the next largest expense as material was required for the qualification structure and mass models. Another significant cost was overhead or indirect costs paid to NPS at the FY2009 rate of 31.59% for every dollar spent. This rate was based on the fact that the funds were transferred from a federal agency, as different rates apply to different sponsors. After labor, equipment and indirect costs, there was very little to allocate toward travel even though the team had a significant amount of travel planned throughout the year. Overall, the expected distribution of costs were as shown in Figure 16.

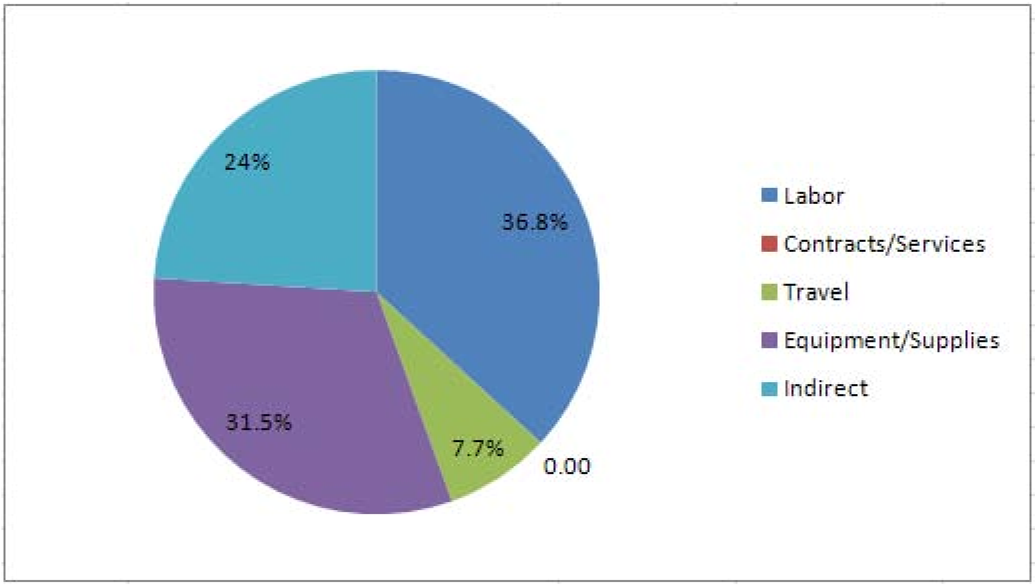

Figure 16. Distribution of Estimated Costs for QbX FY2009 Funds

Fortunately, the PI for the NPSCuL project found other funding, and the money initially allocated to labor was free to be utilized for the quickly growing costs of equipment and supplies and travel. In fact, the team was only able to accomplish so much with such a limited amount of money by heavily leveraging in-house labor. Note that there is a policy that for official travel in support of a sponsored project, labor for the days while on travel must be funded from the project as well [17]. Travel was a significant cost; however, the greatest amount of funds went to equipment and supplies. As the year progressed, the need for various materials increased. In fact, over fifty percent of the funds were spent on equipment and supplies and manufacturing. Surprisingly, the team spent over $6300 on fasteners alone for the structure and mass models as aerospace quality fasteners with certification paper work are quite expensive. The actual breakdown of equipment and supplies costs is depicted in the graph below.

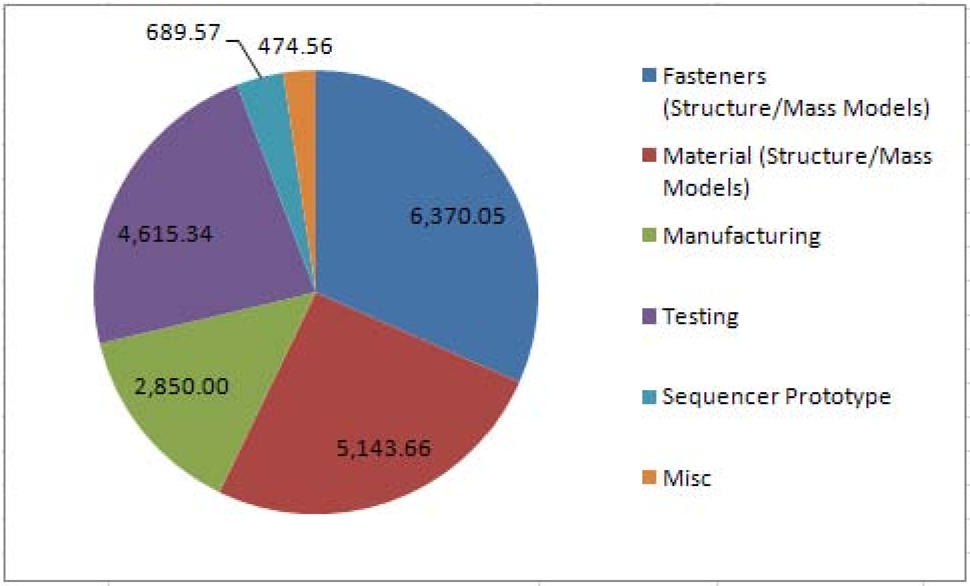

Figure 17. Distribution of Equipment & Supplies Cost ($) for QbX FY2009 Funds

Of importance to note is that the amount spent on testing was $4600. This was due to circumstances outside of the team's control. First, the in-house shaker broke down and repairs had to be made in order to bring it back online. However, rather than wait for the repairs, schedule constraints prompted the team to utilize outside test facilities. Quanta Laboratories, an independent environmental testing laboratory in Santa Clara, CA, agreed to allow us to use their facilities and charged approximately $2500 to produce the test documentation. This was not ideal as it was a significant cost and placed an undue sense of urgency on the team when the initial qualification test went awry, as covered in the lessons learned section.

Travel costs were more than expected as word of NPSCuL-Lite spread. In addition to the expected travel to the CubeSat Developers Workshop at Cal Poly and the Small Satellite Conference at Utah State University, the CubeSat community requested NPSCuL-Lite presentations at both the Boeing Nano-Sat Workshop in Huntington Beach, CA, and at the Government Forum on CubeSats in Albuquerque, NM. On-site technical interface meetings (TIMs) at both the

ULA campus in Littleton, CO, and the Vandenberg AFB launch site accounted for the rest of the travel costs. These meetings were key in maintaining communication and the accurate exchange of information with the launch provider in the absence of a launch systems integration contractor.

Actual Costs	$ (dollars)
Labor	868.87
Contracts/Services	250.00
Travel	8,233.78
Equipment/Supplies	20,143.18
Indirect	9,317.73

Table 7. Actual Costs in $ for QbX FY2009 Funds

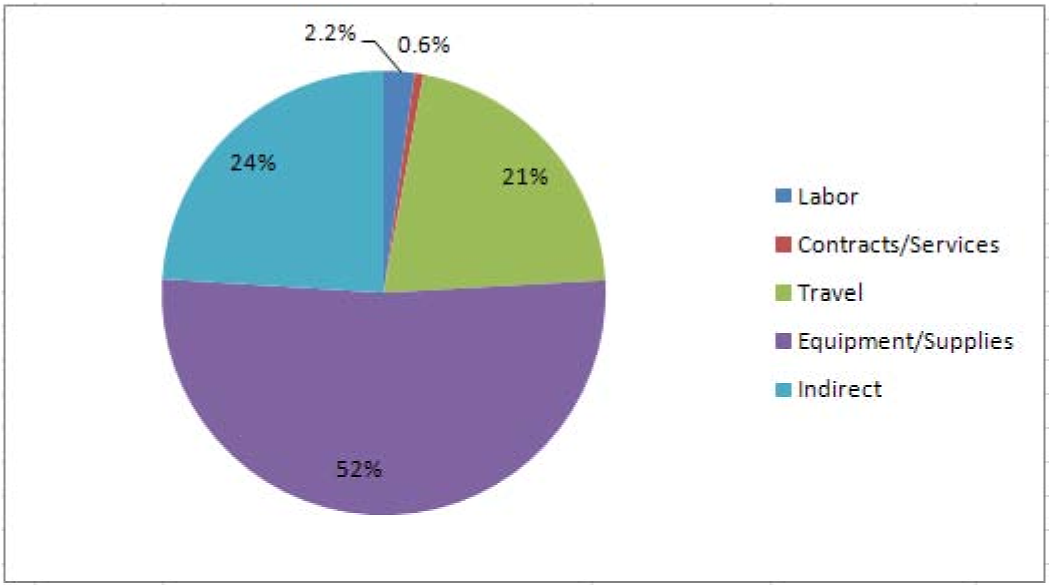

Figure 18. Distribution of Actual Costs for QbX FY2009 Funds

The greatest discrepancies between actual and estimated costs were labor and equipment and supplies. Most of the material and manufacturing costs were estimated by seeking the opinion of more experienced research associates in the Space Systems Academic Group; however, it may have been useful to also consult with potential vendors when creating the budget.

2. CSEWI

As June approached, the program was at risk of running out of funds. Funding from the QbX office was supposed to be forthcoming and a SOW was generated and submitted; however, the funding was not materializing. Fortunately, the Technical Director for the California Space Authority (CSA) was aware of the team's need for funding in order to continue development of the NPSCuL-Lite, with the ultimate goal of supporting university access to space for their CubeSats, while understanding that launch on NRO L-41 would be an important milestone in reaching that goal. He was able to procure $95,000 of follow-on funding through the California Space Education and Workforce Institute (CSEWI) via a grant from the Department of Labor Workforce Innovation in Regional Economic Development (WIRED) initiative. This money was from the same program as the initial CSEWI funding. The WIRED initiative seeks to integrate economic and workforce development activities including talent development [18]. Specifically, the purpose of the funding granted to NPS is to facilitate student and university payload access to space. The NPSCuL-Lite is an ideal recipient of this funding as it provides high capacity low cost access to space for CubeSats as well as aerospace workforce development.

One challenge encountered was due to the fact that the funding could not be transferred via military interdepartmental purchase request (MIPR) from a non-government agency such as CSEWI. In addition to a SOW and budget, a Cooperative Research and Development Agreement (CRADA) was required for the funds to be transferred to NPS. A CRADA serves as the basis for the receipt of sponsored funding from non-federal entities [17, p 4]. Fortunately, a CRADA had been generated when CSEWI provided the original WIRED funds to the NPSCuL-Lite program in FY2008, so the process was shortened significantly in that both NPS and CSEWI only required an update to the previous CRADA for approval. The updated CRADA was routed through the technology transfer office and legal office and approved by the CSEWI General Counsel and the President of the Naval Postgraduate School.

The CSEWI CRADA SOW outlined the following tasks as the responsibility of NPS:

1. Update and deliver a CubeSat Launcher Process and Requirements Document.

2. Produce and qualify an NPSCuL flight structure based upon previous design and qualification work including production and testing of the flight structure and associated activities such as production of mass models and any sequencer work required for the final flight unit and delivery of the necessary documentation.

3. The NPSCuL payload will be attached to an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) compatible launcher and will comprise the flight structure, multiple "P-POD" launchers, and the P-POD sequencer.

The following tasks were listed in the SOW as the responsibility of CSEWI:

1. Provide access to space community resources.

2. Assist with the update of the CubeSat Launcher Process and Requirements Document.

3. Assist/advise with production and test of the NPSCul flight structure.

The SOW also listed the following tasks at the joint responsibility of NPS and CSEWI:

1. Attend appropriate conferences.

2. Produce research reports and papers for possible publication.

After final approval of the CRADA, the $95,000 of funding was made available to the NPSCuL-Lite team under the account name RSPUQ.

	May	June	July	August	September	October	Yearly Total	Target (Set June 2009)
Labor	**0.00**	**6068.70**	**7070.80**	**7363.40**	**6890.40**	**12249.60**	**39,642.90**	**26054.60**
Intern 1	0.00	3062.40	3062.40	3062.40	765.60	0.00	9,952.80	9952.80
Intern 2	0.00	2296.80	3062.40	3062.40	3062.40	6124.80	17,608.80	9952.80
Intern 3	0.00	709.50	946.00	473.00	0.00	0.00	2,128.50	6149.00
Intern 4	0.00	0.00	0.00	765.60	3062.40	6124.80	9,952.80	0.00
Contracts/Transfers	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**450.00**
Registration Fees	0.00	0.00	0.00	0.00	0.00	0.00	0	
Travel	**0.00**	**0.00**	**0.00**	**4,078.21**	**0.00**	**0.00**	**4,078.21**	**15,000.00**
Students	0.00	0.00	0.00	4,078.21	0.00	0.00	4,078.21	
Equipment & Supplies	**0.00**	**6,100.00**	**8,251.00**	**4,951.24**	**0.00**	**636.77**	**19,939.01**	**22,155.55**
a) E&S less than $15k	0.00	2,250.00	3,453.54	2,465.14	0.00	0.00	8,168.68	4,155.55
Structure	0.00	2,250.00	972.90	1,903.50	0.00	0.00	5,126.40	
P-Pod Mass Models	0.00	0.00	2,480.64	0.00	0.00	0.00	2,480.64	
Sequencer Mass Model	0.00	0.00	0.00	561.64	0.00	0.00	561.64	
Harnassing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
b) E&S greater than $15k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
c) Software and support	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
d) Manufacturing	0.00	2,350.00	2,450.00	2,200.00	0.00	0.00	7,000.00	18000.00
Flight Unit/Mass Model	0.00	2,350.00	0.00	2,200.00	0.00	0.00	4,550.00	6000.00
P-Pod Mass Model	0.00	0.00	2,450.00	0.00	0.00	0.00	2,450.00	12000.00
e) Testing	0.00	1,500.00	2,318.46	175.80	0.00	0.00	3,994.26	
Vibration	0.00	1,500.00	2,318.46	175.80	0.00	0.00	3,994.26	
TVAC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
f) Miscellaneous	0.00	0.00	29.00	110.30	0.00	636.77	0.00	
Indirect Cost	**0.00**	**5,990.65**	**7,542.92**	**8,070.20**	**3,392.14**	**6,343.96**	**31,339.88**	**31,339.89**
Total Expenses	**0.00**	**18,159.35**	**22,864.72**	**24,463.05**	**10,282.54**	**19,230.33**	**95,000.00**	**95,000.04**
Actual Cumulative Expenses	0.00	18,159.35	41,024.07	65,487.13	75,769.67	95,000.00		

Table 8. Budget for CSEWI FY2009 Funds

The estimated costs at the beginning of the fiscal year for each category are shown in Table 9. Even though the funding originated with the Department of Labor, it became non-federal money as soon as it passed through CSEWI. Consequently, the indirect or overhead rate charged to the account was 49.23% and accounted for approximately one third of the funds [19].

Estimated Costs	$ (dollars)
Labor	26054.60
Contracts/Services	450.00
Travel	15,000.00
Equipment/Supplies	22,155.55
Indirect	31,339.89

Table 9. Estimated Costs in $ for CSEWI FY2009 Funds

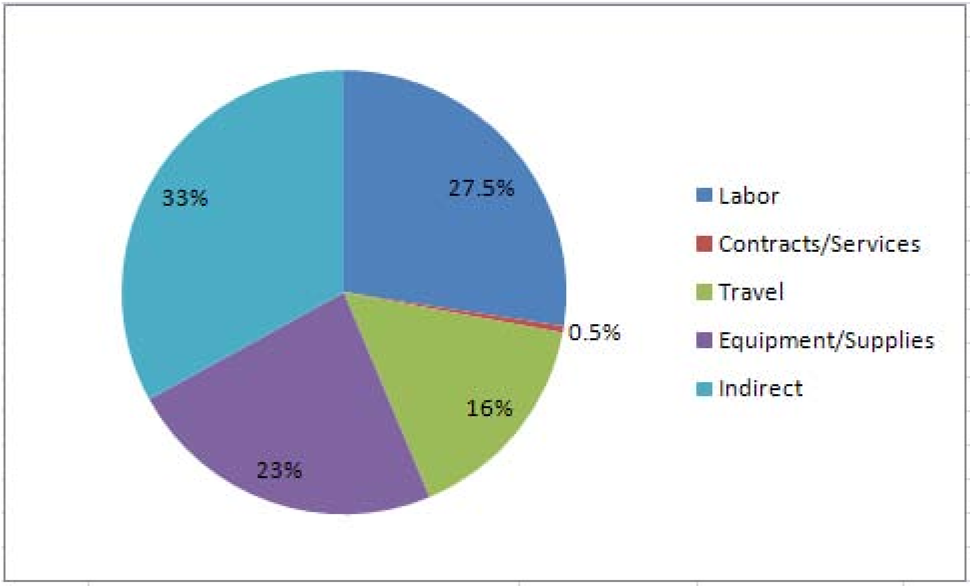

Figure 19. Distribution of Estimated Costs for CSEWI FY2009 Funds

With the exception of overhead, labor was initially determined to be the greatest cost to the project. Due to the departure of three of the four student officers working on the NPSCuL-Lite project, the team decided to hire student interns for the summer in order to provide continuity and keep the program on schedule. Professors at the University of Michigan and Montana State University recommended graduate engineering students who would be interested in working at NPS on the NPSCuL-Lite project. Since the graduate students had their undergraduate degrees and were already accepted to graduate school, they were hired at a GS-05 level under the NPS student temporary employee program (STEP). In addition, a local high school student was hired as an office aide at a GS-01 level under the same program. Under STEP, the students are intermittent employees, meaning that they work a fixed number of hours per week, but they have flexibility in when to work those hours. In addition, the employer is responsible to pay an overhead of 10 percent for labor acceleration [20].

The hiring process was simple from a program management perspective. The prospective employees filled out an application, OF612, and provided a resume, official transcripts and proof of school enrollment. The Human

Resources Office provided the pre-employment package and handled all the paperwork. The only information required from the PM was the paygrade level and start date. Also, the PM was required to sign a timecard for each intern for every pay period for entry into the Electronic Time and Attendance Certification (ETAC) system. This ensured the labor was properly charged to the project account.

The interns proved vital in keeping the program on track. So much so that another graduate student from the University of Michigan was hired when one of the interns had to depart to start graduate school. In addition, one of the summer interns agreed to stay at NPS for a full year. Both of these changes resulted in a significant increase in actual labor costs over what was initially estimated. Having the student interns permitted hugely increased productivity as they are available full time. The hourly rates and resulting overall labor cost including a ten percent overhead rate are shown in Table 6. The table covers student labor costs through October 30, 2009.

			Days	Yr. Effort	Hrly Rate	Estimated Cost
Faculty Time and Salary, for individuals not receiving benefits:						
Intern 1 (GS-05)			65	.27	$ 17.40	$ 9,048.00
Intern 2 (GS-05)			115	.48	$ 17.40	$ 16,008.00
Intern 3 (GS-01)			22.5	.09	$ 10.75	$ 1,935.00
Intern 4 (GS-05)			65	.27	$ 17.40	$ 9,048.00
Subtotal - Faculty Salary and Stipends, for individuals not receiving benefits						$ 36,039.00
Faculty Benefits at	10.00%	(taxes) **Indirect charged on Faculty Time and Salary, for individuals not receiving be**				$ 3,603.90
Labor- Salary, Stipends, and Benefits						$ 39,642.90

Table 10. Labor Cost Calculator for the NPSCuL-Lite Program

Equipment and supplies was another cost that was expected to be significant. The team was able to build a qualification unit structure with enough material remaining for a flight unit using the QbX funds; however, due to the lessons learned from the first qualification test and resulting design changes, more manufacturing and material would be required. Specifically, the design changes called for new P-POD mass models and updates to the structural design and fastener choices. Manufacturing alone accounted for almost fifty percent of the equipment and supplies costs. The manufacturing costs covered machining eight new P-POD mass models (P2M2s) and both qualification and flight NPSCuL-Lite structures. Material for the P2M2s and structures, testing equipment for the shaker, and fasteners accounted for the remaining costs. Overall, the expected distribution of costs were as shown in Figure 20.

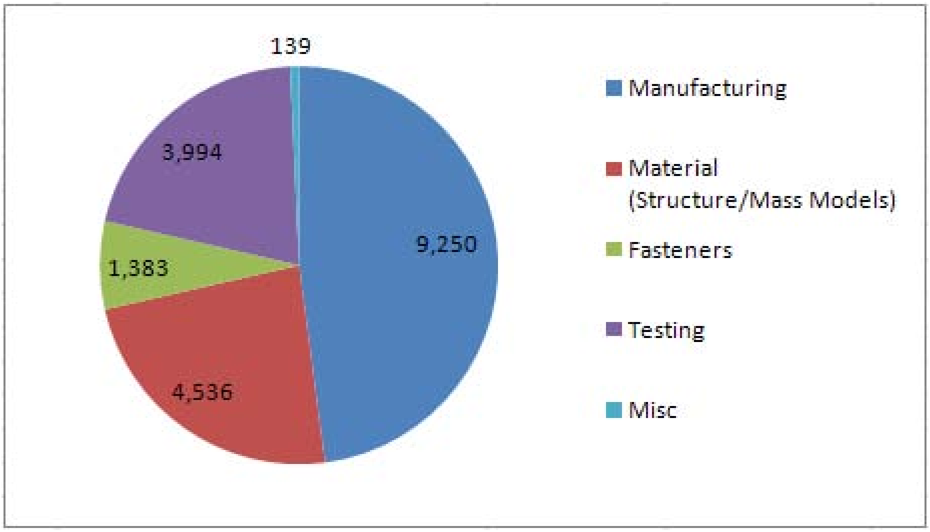

Figure 20. Distribution of Equipment & Supplies Cost ($) for CSEWI FY2009 Funds

Actual travel costs were much less than anticipated. The number of on-site technical interchange meetings was overestimated as most of the technical exchange occurred via teleconferencing. In addition, the PM was able to leverage funds from another account available for NPS student travel to pay for some of the expenses related to the Small Satellite Conference, which normally represents a significant travel cost to the program. Lastly, funds initially set aside for travel were utilized to cover the increased labor costs that resulted from hiring an additional intern.

Actual Costs	$ (dollars)
Labor	39,642.90
Contracts/Services	0.00
Travel	4,078.21
Equipment/Supplies	19,939.01
Indirect	31,339.88

Table 11. Actual Costs in $ for CSEWI FY2009 Funds

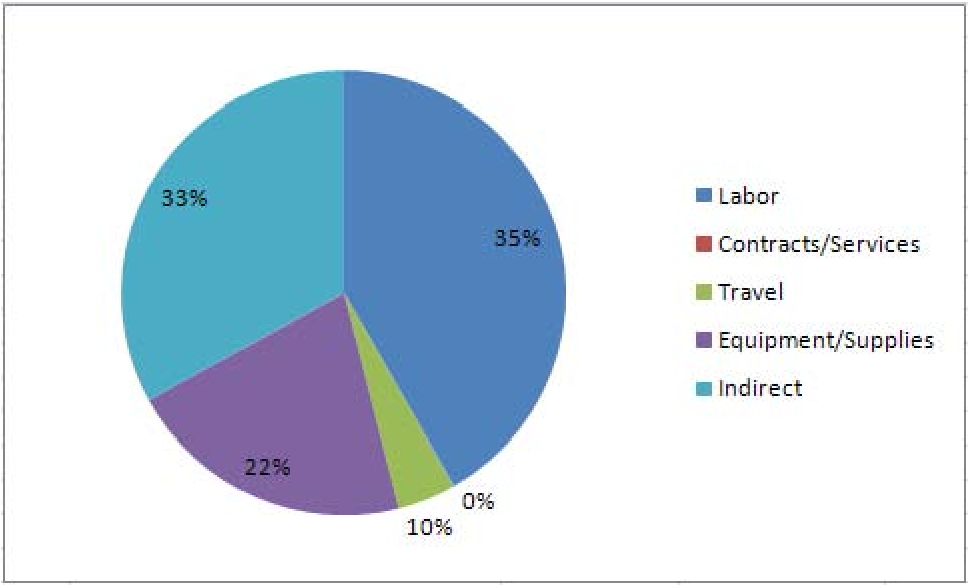

Figure 21. Distribution of Actual Costs for CSEWI FY2009 Funds

Total actual costs are still to be determined as the period of performance for the FY2009 CSEWI funding is actually through the end of October 2009. A period of performance is the timeframe designated for the funding to be executable. Initially, the period of performance was through October 15, 2009, but an extension was requested and approved due to the NPS end of year spending freeze. Basically, it is very difficult for money to be obligated during the month of September in order to facilitate the end of year budget close out paperwork. The extension allows the program to purchase any additional required supplies in October.

One important note in comparing the estimated vs actual costs is the improvement in cost estimating for equipment and supplies. Approximately

$22,000 was estimated for equipment and supplies, and the actual cost was within a few percent of the estimate. This demonstrates the importance of experience and knowledge in creating a realistic budget. The experience of buying material for the first qualification unit provided the knowledge required to accurately estimate the costs for each additional unit.

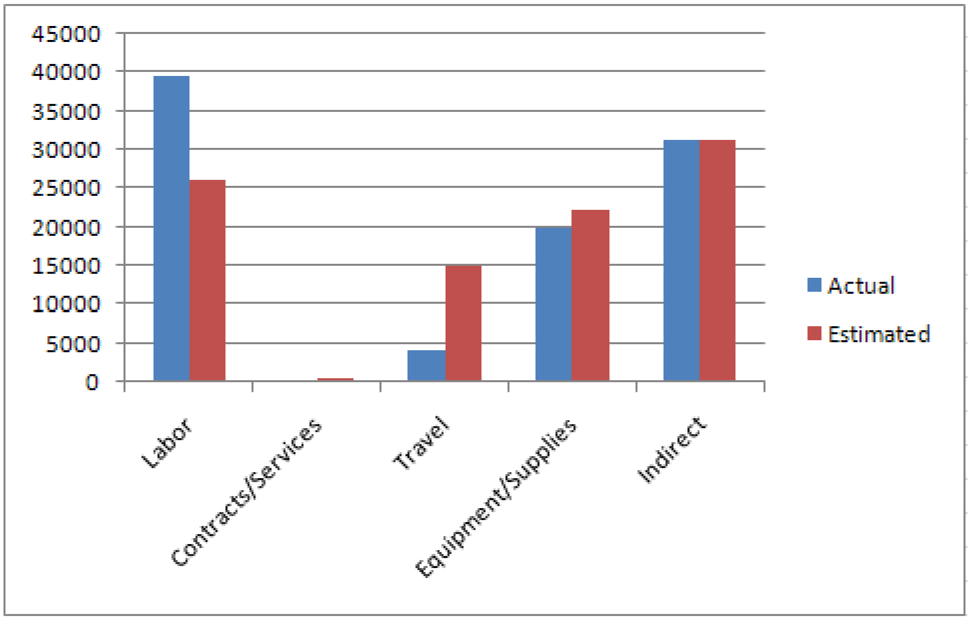

Figure 22. Comparison of Actual vs. Estimated Costs ($) for CSEWI FY2009 Funds

C. LESSONS LEARNED

Managing a budget in a government position is as much about following the rules as about number crunching. The best resource for a PM is the NPS Research and Sponsored Programs Administration website, http://www.nps.edu/Research/rspa.html. This website provides sample budget pages, indirect cost rates per fiscal year, and a wealth of information on contracting for support personnel such as sole source justifications and current NPS Comptroller guidance.

1. Following the Rules

The policies that have the most impact on the PM are those concerning the use of the government commercial purchase card. This card is the means by which the Purchasing Agent (PA) makes micro-purchases on behalf of the PI/PM. Micro-purchases are defined in the Federal Acquisition Regulation (FAR) [21] as the acquisition of supplies or services using simplified acquisition procedures, the aggregate amount of which does not exceed the micro-purchase threshold of $3,000. NPS Comptroller guidance [22] further defines the micro-purchase threshold as $3000 for supplies; $2500 for services; and $2000 for construction under the appropriate conditions. Micro-purchases do not require multiple quotes. For a purchase request of greater than $3000, the buy must be competed with a deliverable of three or more quotes. These quotes must be included with the purchase request. The PA then completes a best value determination worksheet based on the quotes and any other factors that were considered in choosing a vendor. If it is not possible to get at least three quotes for a purchase, then a sole source justification must be generated and signed by the end user or PM. The sole source procurement is a lengthy process, i.e. greater than a few weeks, as it must be forwarded to the Fleet and Industrial Supply Center (FISC) San Diego for approval.

Lastly, hazardous materials can be purchased only in the small volumes that are customarily sold to the general public [22, p 56]. All hazmat purchases must have the approval of the Safety Officer or be on the on-base Authorized Use List (AUL). This means that the PM should submit all purchase requests for hazmat to the GSEAS Research Associate and Safety Officer in addition to the SPFA. This can result in a delay of a few days for the ordering of the material.

2. Budget Changes

Sometimes it becomes necessary to make updates and changes to the budget from what was originally proposed. This occurs when actual expenses exceed estimated expenses for a specific category such as equipment/supplies.

It is the responsibility of the PM to initiate a budget page change with a request to the SPFA and to justify the revision. Generally, the request for a revised budget is stated as follows, “Move $[dollar amount] from [Category A] to [Category B]. Move $[dollar amount] from [Category A] to [Category C]. Justification for budget change request is an increase in actual costs over budgeted costs for [Category B] and [Category C].” Upon approval from the requisite Department Chair, the SPFA then submits the budget page change that delineates the modifications to the approved expenditure control page. A copy of the request for revised budget is in NAVPGSCOL Instruction 3900.1C.

3. Having Extra Material on Hand Now Saves Time Later

Through the process of procuring the necessary material for the NPSCuL-Lite project, the team generally orders more material than is needed. This is acceptable per the NPS instruction on Financial Management and Accounting Procedures [16, p. 19], which states, “Purchasing goods for inventory, the consumption of which may occur beyond the current fiscal year, is also acceptable, provided that the inventory is not excessive.” This practice has proven itself useful over and over again. There have been several instances when having inventory on hand has saved considerable time. One example involves the sequencer mass model. When the original sequencer mass model material was ordered, the team submitted a purchase request for twice the material needed, i.e., enough for two sequencer mass models. Subsequently, an error in a drawing caused the sequencer mass model to be manufactured incorrectly. The machinist was able to correct the mistake by elongating the mounting holes on the mass model for the first qualification test; however, the team decided a new mass model with accurate mounting hole diameters would be preferred for the second qualification unit. Since there was material on hand for the manufacturing of a second sequencer mass model, the team did not have to wait for the material to be ordered and delivered.

4. September Freeze

One surprise concerning the budget was that no funds could be committed after August 31, 2009 in support of FY2009 end of year budget close-out. Every year the NPS Comptroller issues year-end closing guidance that establishes the "purchase action cut-off date" in order to facilitate a timely and orderly close at year-end [16, p 40]. The SPFA sent notice of the FY2009 year-end financial closing cutoff procedures on July 23. A memo from the Comptroller dated May 12, 2009 [23] states that "All purchase requests must be submitted to SPFAs by 31 August 2009." Due to this spending freeze for the month of September and possibly part of October, the team had to make decisions about what material was needed during that timeframe and submit the purchase requests by close of business on August 31. Since vibration testing is scheduled for the month of September, the team had some difficulty in trying to determine what could go wrong and what material would then be needed. The challenge is that the shaker might break again, and the team would not be able to order any parts required to repair it. Worse yet may be that an unforeseen issue arises that would require the team to wait until October when the commitment of funds is again authorized in order to advance the project.

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III. SCHEDULE

A. PROGRAM SCHEDULE OVERVIEW

1. Optimistic

The schedule for NPSCuL-Lite was built using the Microsoft Project program. The initial program schedule for NPSCuL-Lite was determined without any collaboration with the launch provider or integration manager. The initial schedule was optimistic at best (naïve at worst) with a target delivery date of a flight ready structure at the end of September 2009. This target date was based on an initial Sponsor requirement provided by the QbX office. The initial receipt of funding was in October of 2008, which represented a development timeline of less than a year. Any type of collaboration with the launch provider did not occur until late in the fourth calendar quarter of 2008. The initial schedule is in Appendix D with a high level overview shown in Figure 18.

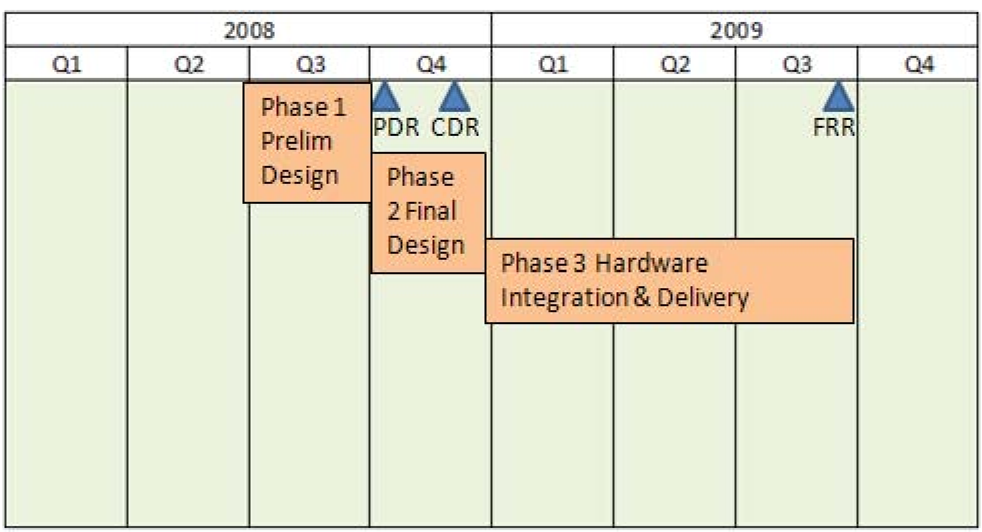

Figure 23. Initial Schedule Overview for NPSCuL-Lite

Prior to receipt of funding, a significant amount of conceptual and preliminary design work was completed which is incorporated in the preliminary design phase. Final system design including the completion of drawings was expected to take two months from receipt of funding with a CDR planned for the first week of December 2008. The team expected to procure hardware and build the qualification unit in two months. The qualification testing, including vibration, shock, thermal vacuum and functional tests, was scheduled for the months of February through May 2009. The flight unit hardware procurement and build was expected to be complete by the end of July with acceptance testing complete by mid-September. After a flight readiness review (FRR), a flight unit was scheduled to be delivered to the Sponsor for integration by the end of September 2009.

Amazingly, the team was able to design, build and test a qualification unit within the initial timeframe. This was due entirely to the fact that the estimated time for testing the qualification unit was grossly overestimated. The initial time frame for qualification testing was 77 working days or almost four months. At the time of the generation of the first schedule, no launch vehicle ICD was available that listed the testing requirements. The team received initial environmental test requirements at the launch provider PDR in December 2008. At that time it was made clear that the only requirement was static and random vibration testing which encompassed the shock parameters. Actual experience showed that vibration testing could be accomplished in a few weeks including preparation time. In the end, this gross overestimation provided the schedule margin needed to account for the delays described in the next section.

B. CHANGES

The problem with the schedule was that it did not take into account Murphy's Law, that "anything that can go wrong, will go wrong." "Whether we must attribute this to the malignity of matter or to the total depravity of inanimate things, whether the exciting cause is hurry, worry, or what not, the fact remains" [24]. Schedule slips were caused by the inherent make-up of the team, preventable oversights, and issues outside of the team's control. Another source of schedule delay was the NPS procurement process.

1. Experience, and the Lack Thereof

One of the main issues driving the schedule was the number and inexperience of the student team members. The team was comprised of four students with only one of those students working on the project full-time. The other three students had to juggle coursework and homework in addition to work for the project. This resulted in longer timelines for the completion of deliverables such as drawings and procedures.

In addition, none of the student team members had any experience building space hardware, so there was no inherent knowledge in the core members of the team. Although some input was sought from experienced faculty members in the building of the schedule, the team simply had no idea the length of time required for certain activities. Furthermore, mistakes were made in material and fastener selection that demonstrated the team's lack of knowledge and led to schedule delays. For example, the team decided to utilize locking threaded helical inserts and flathead countersunk screws, only to find out later that neither are recommended for our intended use (based on personal communication with aerospace professionals, although opinions differ on this point). Also, the failure to ensure flat mating surfaces for the mass models was definitely a rookie mistake, facilitated by the perceived schedule urgency. All of these mistakes resulted in the failure to successfully qualify the first structure and, consequently, a significant schedule slip.

To further compound matters, the team had only one team member with any structural design experience. The rest of the team had to learn the computer-aided modeling programs, IDEAS and NX, from scratch. The time allotted for this training was thirty days, but in reality, it was an iterative lengthy process for the team to become proficient enough to develop models and drawings in the programs on their own. In the end, the simplicity of the NPSCuL-Lite design permitted the team to overcome these obstacles and progress towards making real flight hardware.

2. Shake and Break

Some events that resulted in schedule delays were outside of the team's control: the most notable of which being the unavailability of the NPS large electrodynamic shaker. During initial testing of the NPSCUL-Lite shaker plate or vibration test fixture in mid-May, the shaker malfunctioned. Since replacement fuses had to be procured in order to fix the shaker, the initial estimate for completion of repairs was at least two weeks. The Test and Integration Manager was scheduled to graduate in June of 2009, so the team worked to facilitate the completion of vibration testing prior to his departure. The result was the utilization of the facilities at Quanta Laboratories, an independent environmental testing laboratory in Santa Clara, CA.

The unavailability of the shaker continues to be an issue for the NPSCuL-Lite schedule. The shaker was moved from temporary facilities to a lab on the main floor of Halligan Hall. Unfortunately, this space required extensive renovation in order to be adequate for the needs of the NPS Small Satellite Lab. Due to delays in contracting for the flooring replacement and electrical panel upgrades, the shaker availability has slipped from August 1 until late September, 2009.

3. Realistic

The actual program schedule to date is in Appendix E. A high-level overview is shown in Figure 19 below. The schedule overview shows both the NPSCuL-Lite activities in orange and blue and the ULA activities in purple. The preliminary design phase incorporates all of the work done up to the first qualification test. The failed qualification test truly drove the program schedule afterwards in that significant time was required to investigate, redesign and begin the process of building and qualifying a structure anew. Fortunately, by that time, the team had insight into the launch vehicle schedule which did not require delivery of a flight ready NPSCuL-Lite until January or February of 2010. Additionally, from a student perspective, the failure of the first qualification test resulted in a tremendous opportunity to learn and the recovery effort itself provided an outstanding educational opportunity.

Upon the conclusion of the investigation into the failure of the first structure to qualify, some redesign was done. A design review (DR) was held on June 17, 2009 to present and debate the goodness of every single design change. Once the team felt confident in the updated design and fastener choices, it moved into a final design phase in which models and drawings and a fastener analysis were completed. Due to the success-oriented nature of the schedule, hardware procurement and manufacturing and integration activities were completed in parallel with the design and analysis efforts. This allowed the team to build hardware prior to completing analysis.

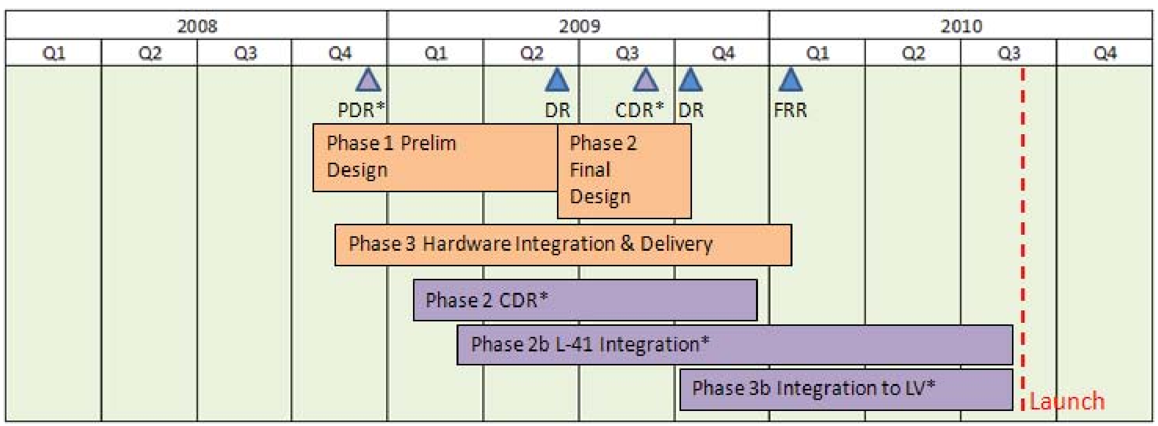

Figure 24. Updated NPSCuL-Lite Schedule Overview

Although the qualification of the first hardware build was not successful in the traditional sense, this parallel path was tremendously successful in that the student team members learned significant lessons that are captured in the lessons learned section under Program Management. The lessons learned from the qualification failure truly allowed the team to move forward in the direction of goodness a little wiser with a more realistic plan of action and schedule.

As of the date of this thesis, the second qualification unit of the NPSCuL-Lite has been manufactured and assembled. Updated P-POD and sequencer mass models have been completed and integrated onto the NPSCuL-Lite structure. A tap test at CSA Engineering is complete, primary modal frequencies determined for the coupled loads analysis, and the next step is integration of two P-POD EDUs and application of the staking compound at least 24 hours prior to vibration testing. As with the first qualification test, the results of the next round of vibration testing will truly determine the path forward.

C. INTEGRATION

The NPSCuL-Lite schedule is actually a small part of a much larger activity. The NPSCuL-Lite schedule is part of the ADaMSat schedule which is part of the ABC schedule which is part of the NRO L-41 Centaur schedule. This means that there are larger program milestones that the NPSCuL-Lite must meet. Prior to the LSIM joining the team, the NPSCuL-Lite team was working directly with the launch provider in order to keep track of required deliverable deadlines and integration milestones. The NPSCuL-Lite milestones being tracked by the launch provider were extremely conservative at the time they were provided. For example, the launch provider estimated that the NPSCuL-Lite environmental testing would be complete by November 1, 2009.

⊟ Env Testing	**169 days**	**Sun 8/9/09**	**Thu 4/1/10**
Vibration	0 days	Sun 8/9/09	Sun 8/9/09
Shock	0 days	Sun 9/13/09	Sun 9/13/09
Thermal Vac	0 days	Sun 11/1/09	Sun 11/1/09
Harware Ship - NPS	0 days	Thu 4/1/10	Thu 4/1/10

Table 12. NPSCuL-Lite Milestones as Tracked by ULA

Once onboard, the LSIM took on the responsibility of coordinating directly with the launch provider, so that the NPSCuL-Lite team now coordinates directly with the LSIM. This means that the LSIM drives the ADaMSat schedule and requests inputs and deliverables from the different ADaMSat projects, including NPSCuL-Lite, in time to deliver them to the launch provider. Conversely, the NPSCuL-Lite team is responsible for keeping the LSIM updated on the most current schedule of events and any issues that could cause schedule delays. The closer the program gets to integration with the launch vehicle, the more impact a schedule slip within the NPSCuL-Lite program would have on the ADaMSat program. The ADaMSat milestone schedule provided by the LSIM is shown in Table 13.

Milestone	Start	Finish
ADAMSat Kick-off Meeting	7/7/09	7/7/09
Sequencer CDR	8/18/09	8/18/09
CubeSat MDRs		9/1/09
ADAMSAT CDR	9/24/09	9/24/09
Eng. P-PODS Ship to CubeSats		10/25/09
CubeSat Qualification Testing	9/15/09	12/24/09
CubeSat Qual Report		12/31/09
CubeSat Ship to Cal Poly	1/15/10	1/20/10
Sequencer Build	8/3/09	10/23/09
Sequencer Test Readiness Review	10/23/09	10/23/09
Sequencer Protoqual Testing	10/26/09	12/4/09
Sequencer Ship to NPS	11/30/09	12/4/09
NPSCuL-LITE EDU Build	6/18/09	8/21/09
NPSCuL-Lite EDU Qual Test	8/24/09	9/17/09
NPSCuL-Lite EDU Post Qual Test Rev.	9/24/09	9/24/09
NPSCuL-Lite Flight Build	9/25/09	10/23/09
P-POD/CubeSat Integration	1/20/10	2/5/10
P-POD Assym. Acceptance Tests	1/22/10	2/9/10
P-POD Assym Ship to NPS	2/12/10	2/20/10
Sequencer Deployment Seq Defined		2/22/10
ADAMSAT Component Integration	2/22/10	3/12/10
ADAMSAT Acceptance Tests	3/15/10	4/5/10
ADAMSat Ship to VAFB	4/9/10	4/11/10
ADAMSat Integration with LV		4/16/10
ADAMSat Prelim MSPSP Inputs		**9/15/09**
ADAMSat Prelim ODAR Inputs		**9/15/09**
ADAMSAT VLC CLA Model		**10/1/09**
ADAMSAT Final MSPSP Inputs		**2/1/10**
ADAMSat Final ODAR Inputs		**2/1/10**
ADAMSat Matchmate with ABC		**2/15/10**
ADAMSAT Pathfinder		**1/15/10**

Table 13. ADaMSat Milestone Schedule

D. LESSONS LEARNED

One area for improvement in program implementation in the future is to try to anticipate what can go wrong and develop corresponding plans of action. The team did not do enough brainstorming of worst-case scenarios. This was readily apparent after the fastener failure during the first qualification test. Part of the team was at Quanta Laboratories in Santa Clara, where they had only two days to conduct the vibration test, so there was an undue feeling of pressure to complete the testing in that timeframe. Consequently, when the failure occurred, the team decided to remove all the exposed countersunk flathead screws and replace them with socket cap screws and washers and continue with testing, rather than stop the test and consult as to what should be the next step. In hindsight, this may have not been the right thing to do, in that it made the failure investigation more difficult. This mistake could have been avoided if the team had decided beforehand what the proper course of action would be in the event of a failure. For the next qualification test, the team is building a contingency plan into the test plan. The contingency plan delineates the criteria for pass/fail of the vibration testing. Failures are categorized as either yellow or red. A red failure—such as a break in the staking compound, or worse—would result in a complete stoppage of the vibration testing. A yellow failure, such as a 5 to 10 percent excursion in the frequency output during a sine sweep, would result in a temporary stoppage of the vibration testing in order to consult as a team as to the next step. It is also in the team's best interest to accept some schedule delays, if necessary, in order to use in-house test facilities.

Another lesson learned is to always build margin into the schedule. The program manager needs to accommodate unforeseen issues that tend to arise. One recommendation is to decide realistically how much time is required to complete an action, and then add at least a week or more depending on the complexity of the action.

One other issue that keeps coming up, even as the program nears integration with the launch vehicle, is the opportunity to change the design. The NPSCuL-Lite design is simple, in that very little mass optimization or structure stiffening has been done. Unfortunately, the first several fundamental frequencies are lower than the 100 Hz that the launch provider would prefer and there is little mass margin available for CubeSat developers who would like to deliver CubeSats that weigh more than the accepted standard. In addition, the new sequencer vendor, Ecliptic Enterprises, may deliver an ADaMSat Sequencer Box (ASB) that is lighter and has a smaller footprint than the MIPS designed by Design_Net. This design change could possibly uncover some of the P-POD mounting holes on the sequencer wall, thereby removing the requirement to use the countersunk flathead screws in those holes. For these reasons, there have been multiple requests by the LSIM and others to consider re-design. Although the NPSCuL-Lite team acknowledges the potential advantages of these design changes, and would be glad to implement them, time permitting, the fact is that the program schedule cannot support changes to the design at this point in the process. Any changes to the design represent an enormous schedule and budget risk that could endanger the on-time delivery of ADaMSat to the launch provider. Additionally, any proposed slip to the schedule of the primary payload cannot be used to justify design changes. The program has to move forward per the original schedule until such a time, if ever, that the delay becomes official. The point is that for the NPSCuL-Lite team, the decision had to be made to freeze the design and work diligently to convince others not to make changes. The goal should be to optimize the NPSCuL-Lite design for the follow-on to a successful ADaMSat launch.

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IV. PROGRAM MANAGEMENT

A. RISK

One of the main responsibilities of the program manager is to identify and manage program risk. NPSCuL has always carried risk in several areas including budget, schedule, and technology.

1. Budget

The budget presented a significant challenge as only minimal funding was available until recently. In fact, the first qualification unit was built on a budget of only $39,000, provided by NRO AS&T QbX office, by heavily leveraging in-house capabilities. Also, significant cost savings were realized in travel by flying in and out of San Jose to take advantage of their lower airfares. Despite these cost-saving measures, the program was under serious risk of running out of funds and being unable to continue development work. Further increasing the risk was the graduation of three of the four student officers working on the project, whose salaries are paid by the DoD. Critical relief was provided when the California Space Education and Workforce Institute (CSEWI) provided the additional $95,000 for the second qualification unit and the flight unit. The student interns hired using these funds quickly became indispensable as they are able to devote forty hours a week to the project, but the hiring of interns meant that the program developed significant labor costs. Consequently, funding the interns past the CSEWI period of performance became another risk area. The interns had deferred commencing their graduate educations at their respective home universities in order to work on the NPSCuL-Lite project, so ensuring their salaries would be available was an important issue. The only other option was to attempt to identify alternate sources of funding in the event that funding from the ADaMSat Program, a user financed project, was not available by the end of October. ADaMSat is a user-financed project in that the users, or CubeSat developers, pay their contribution directly to the ADaMSat developers rather than to QbX for redistribution. Fortunately, the NSF contribution for the flight of FireFly was MIPR'd to NPS at the beginning of September, enabling uninterrupted support of the ADaMSat project.

2. Schedule

The schedule is also a major risk area as it is success-oriented. The timeline for development was only sixteen months from beginning to the required delivery date of a flight-ready unit in time for a proposed flight in August 2010. The schedule risk was exacerbated by two significant issues. First, despite significant QbX efforts, no integrating contractor was able to be brought online to facilitate technical interchanges and coordinate documentation and hardware deliverables. A launch systems integration manager (LSIM) was placed on contract in July, only six months prior to delivery of flight hardware. Second, the flight specific launcher-payload ICD for the proposed flight was also not available until fairly late in the integration process. In fact, the first ICD review was not held until mid-June. Without an accurate launcher–payload ICD, the program moved forward under significant technological risk as the team could not be certain that the design and qualification testing met the launch provider's requirements. In order to mitigate this risk, the NPSCuL-Lite team maintained frequent communication with the launch provider in order to have open technical interchange and keep the launch provider apprised of the technical specifications and launch environments that the team was following. Some requirements, such as the SP envelope and mass restrictions, were set forth in the ABC Preliminary Design Review (PDR) held in December 2008. At that time, a significant miscommunication resulted from the lack of a payload integrating contractor. During the ABC PDR, the NPS team briefed the status of the NPSCuL-Lite project. The previous student program manager mentioned that the preliminary analysis of a finite element model of the NPSCuL-Lite structure showed that the fundamental frequency was approximately 100 hertz (Hz). The launch provider subsequently used this number in a preliminary coupled loads analysis (CLA) that was completed in support of the L-41 launch. When the NPS team announced at the Rideshare conference in May that the initial qualification test of the integrated structure and mass models showed a first modal frequency of about 60 Hz, the launch provider became alarmed as this, along with a lowering of the ADaMSat center-of-mass, invalidated their completed CLA. After consulting with the personnel involved in determining the launch vehicle loads, it was decided that NPS would provide a worst case fundamental frequency based on a finite element model of the integrated structure (approximately 50 Hz), and the launch provider would re-run the CLA. The result was that a substantial amount of resources, including funds and manpower, was spent to correct the original miscommunication.

3. Technical

Once the ICD was finalized in July, the primary technical risk became ensuring that the NPSCuL-Lite be structurally sound and capable of supporting the P-PODs, sequencer, and cables. A secondary risk is the use of countersunk flathead screws. Due to the risk posed by the significant surface area between the countersunk screw head and the structure, resulting in inaccuracy in knowledge of the applied torque or preload, these screws may not be the best choice for the NPSCuL-Lite. Unfortunately, the design of the NPSCuL-Lite with the sequencer mounted on the exterior of one of the walls over some of the mounting holes for the P-PODs on that wall left no other fastener choice. In order to mitigate this risk, socket head cap screws were chosen for all fasteners with the exception of six P-POD mounting holes beneath the sequencer. A more in-depth discussion of fastener choices is in the lessons learned section.

Another technical risk is posed by the sequencer. Early in the process, the NRO QbX office and NPS team determined that a commercial sequencer would be required in order to meet the tight timeline required for integration in the L41 launch. Unfortunately, several challenges presented themselves in procuring a sequencer. Initially, Design_Net was identified as a prospect since they were already on contract with ULA to build similar hardware. The challenge lay in how to route funding to Design_Net for an ADAMSat specific mission. Design_Net moved forward with design and development with interim funding with the understanding that balance of funding would soon follow. Based on this understanding, NPS used the Design_Net Multiple Interface Payload Sequencer (MIPS) specification as the basis for the placement of the sequencer mounting holes on the NPSCuL-Lite structure as well as the mass model used in qualification testing. At the CubeSat Developers Workshop, it was brought to the attention of the NPS team that a second vendor was in consideration to build the sequencer. This vendor, Ecliptic Enterprises, would soon be under contract by DARPA to develop similar hardware, so they were chosen as a back-up to the MIPS. In August of this year, to the surprise of the entire team, Ecliptic was chosen to be the primary vendor for the sequencer, based on funding availability from DARPA to support the design and production process. Design_Net was moved to the back-up position due to the difficulty of getting funding to them. The issue then became one of whether to continue towards qualification testing with the mechanical interface and mass model designed for the MIPS or risk schedule slip to redesign both to accommodate the form factor of the Ecliptic sequencer. In order to mitigate any schedule and technical risks, a compromise was reached in the first sequencer technical interchange meeting (TIM) to permit the Ecliptic sequencer form factor to be different than the baselined D-N form, but to place it on an interface plate to maintain the mechanical form factor of the MIPS. It was decided that although the MIPS mass model was significantly heavier than the Ecliptic sequencer, this additional mass would provide a margin of safety in the structure qualification testing and be a stand-in for the cabling and harnessing that would eventually be attached to the structure.

The risks inherent in the NPSCuL-Lite program are intensified by the fact that the L-41 launch will be the very first flight of both the ABC and ADAMSat. By managing these risks and challenges, student program managers gain a valuable real-world education in spacecraft development, launch integration and program management complete with real world stress, anxiety, and excitement.

B. LESSONS LEARNED

During the initial qualification test of the NPSCuL-Lite, fasteners backed out of the mass models seemingly effortlessly, as if unscrewed by some unseen hand. The mass model came loose and banged about the interior of the NPSCuL-Lite structure. Fortunately, NPS is an educational environment and the qualification test was seen as an opportunity to learn rather than as just a failure. In the process of investigating the root causes of the failure to qualify the first NPSCuL-Lite, the NPS team learned a great deal. These lessons learned included the importance of fastener analysis, flat mating surfaces, process reviews, and soliciting the advice of experienced aerospace professionals.

1. In the Direction of Goodness

The first order of business in the investigation was a methodical disassembly of the NPSCuL-Lite. Understanding fully what happened in the first qualification test was made more difficult by not having a contingency plan in the event of a failed qualification test. Since the team had not discussed the proper course of action should a failure occur, after the P-POD fasteners came out during the intial vibration test, the team decided to immediately remove all of the exposed countersunk flathead screws and replace them with washers and socket head cap screws. Due to this action, some information—in particular, pre-load values about the state of the structure after the initial vibration—was lost. After the second vibration, the team measured the remaining pre-load of each fastener prior to removal using a torque wrench. These pre-load measurements were recorded, and pictures were taken of any damage to the fasteners and structure. From witness marks discovered in this investigation, it was determined that the most likely cause of failure was improperly-machined P2M2 mating surfaces, resulting in gapping between the NPSCuL-Lite structure and the P2M2s. A secondary problem was determined to be the use of locking helical threaded inserts that probably prevented an accurate reading of pre-load applied to the fasteners. Both of these conclusions were based upon evidence discovered in disassembly of the structure along with consultation with aerospace professionals, including Cal Poly, ULA, and CSA Engineering. An in-depth description of the initial qualification test and post-test investigation can be found in Adam DeJesus's thesis, titled "Integration and Environmental Qualification Testing of Spacecraft Structures in Support of the Naval Postgraduate School CubeSat Launcher Program" [25].

The important questions from a program management perspective were, "What went wrong?" and "How do we move forward in the direction of goodness?" Once there was confidence in the investigation conclusions, several meetings were held to discuss the answer to the latter question. Normally, it would be desirable to identify a failure mode and make only the minimum design changes necessary to correct that discrepancy. In that way, retest would be able to confirm the suspicion of what caused the failure. Unfortunately, more than one failure mode was suspected, so the team had to make several design changes in one iteration in order to minimize schedule risk and correct all of the noted discrepancies. The flip side of this decision was in the increased technical risk, since this path would not allow for verification of the investigation conclusions. In order to minimize this technical risk, the team decided on one rule: every design change decision must be in all ways in the direction of goodness.

2. Keep it Simple

The first issue was the mass models, referred to as P2M2s . Disassembly of one of the qualification P2M2s showed significant loss of pre-load in the fasteners. In order to minimize the risk of P2M2 failure in the next round of qualification testing, it was decided to simplify the P2M2 design and thereby remove any requirement for fasteners holding the P2M2 structure together. In addition, looking at the witness marks on the NPSCuL-Lite walls showed that the mating surface of the P2M2s were not flat. This would have resulted in a gapping effect that most likely caused the fasteners to lose pre-load and come out. The follow-on, simplified P2M2 design would also incorporate rails with a flatness specification of +/- 0.005 that would provide a more flight-like mating surface. The result of these changes is a simplified mass model with a mating surface that mimics the actual P-POD mating surface. As an additional step in the direction of goodness, the NPS team decided to add two additional mounting holes for the NPSCuL-Lite structure to P-POD mating surface for a total of eight mounting holes.

3. "For Want of a Nail"

The second issue was the fasteners. The original design of the NPSCuL-Lite used countersunk flathead screws for the bracket to wall and wall to P-POD interfaces. The wall to base plate and interface ring to base plate fasteners are socket head cap screws. This decision to use countersunk flathead screws was driven by the requirement to have a flat mounting surface for the sequencer where it is mounted over some of the wall to P-POD mounting holes. Although the team did not have the means to verify whether the countersunk flathead screws would hold with proper pre-load and flat mating surfaces, the consensus from the aerospace professionals consulted was that there was too much performance uncertainty based on the large surface area between the head of the countersunk screw and the structure. Based on this knowledge, the team decided to restrict the use of these countersunk flathead screws to the mounting holes beneath the sequencer so that all other fasteners utilized on the structure are socket head cap screws. Additionally, based on a recommendation from an engineer at CSA Engineering, a thread lock will be used for the countersunk flathead screws in lieu of locking threaded inserts or staking compound.

The team also previously chose to use locking helical threaded inserts. Notably, the locking helical threaded inserts were covered with a pink substance when the machined parts of the structure arrived from Inter-City Manufacturing.

The team spent hours cleaning these threaded inserts with isopropyl alcohol in order to remove all of the pink substance. Later, in preparation for manufacturing the second qualification unit, the team contacted the machinist and requested that the threaded inserts be clean prior to delivery. The machinist then informed the team that the pink substance was in fact supposed to be there as it is an expensive type of grease that permits a more accurate reading of pre-load when using the locking inserts. Upon further research on the manufacturer's website, the team came across an article [26] indentifying the pink color as a red dye required for identification of the inserts as locking. This dye can be removed with alcohol, which is preferred as it is just printer's ink that will outgas. The fasteners were lubricated prior to installation, so it is unknown if the use of locking helical threaded inserts may have been a contributing factor in the failure of the fasteners. Based on several recommendations from the aerospace community, including Cal Poly, the team decided to use free running helical threaded inserts in conjunction with a staking compound. The free running threaded inserts should allow for more accurate measurements of pre-load.

Finally, in order to determine the correct pre-load required for each of the fasteners, a detailed fastener analysis [27] was performed on the load bearing structural elements of the NPSCuL-Lite structure. The fastener analysis was done by applying a static acceleration load to a finite element model of the NPSCuL-Lite structure with point masses for the P-PODs and sequencer. The analysis showed greater than zero margins of safety for the tension, shear, and tension and shear interactions, and gapping. In addition to determining the proper pre-load for each fastener, the analysis also ensured that the threaded inserts used by the structure were of adequate length to ensure failure of the fastener before threaded insert pullout. The assembly and integration procedures were subsequently updated to reflect the results of this fastener analysis. This was the first fastener analysis performed, so the importance of completing the fastener analysis prior to the testing of hardware is a lesson learned.

4. Gun-shy

After making the modifications to the design of the structure, the second NPSCuL-Lite was manufactured. The team received the manufactured walls, base plate and brackets and placed them in storage while waiting for the arrival of fasteners and completion of the assembly and integration procedures. Upon assembly of the structure, it was discovered that one of the walls was bowed with a maximum gap of 0.032." This resulted in the wall and bracket holes not aligning, and the team was not able to easily insert some of the bracket to wall fasteners. Upon investigation of the rest of the materials, it was determined that the base plate was also not flat. The team did not discover this until assembly because a quality assurance inspection of the delivered manufactured parts did not include a determination of the flatness of the parts. More importantly, this condition existed because the material ordered for these parts was rolled aluminum plate stock which has a low standard flatness tolerance. Since the stock was ordered in the exact thickness desired, there was no margin for the machinist to grind the material to a precise flatness tolerance. There are two possible remedies for this issue. One is to order thicker material that can be ground to a high flatness tolerance by the machinist; however, this would add a significant cost to the total machining price. The second solution is to purchase stock that is already precision ground to a high flatness tolerance on the order of +/- 0.002. On the McMaster-Carr website, this material is approximately twice the cost of the rough aluminum sheets, but it is still a cost savings over paying the machinist to do the work. At the time of this writing, an order has been placed for precision ground aluminum sheets for the flight unit. As for the qualification unit, the team has completed assembly and integration with the parts on hand. With integration complete, the team used feeler gages and determined that the P2M2s are flat against the NPSCuL-Lite structure. Based on this and consultation with aerospace professionals, the team will proceed forward with testing. Although the team may just be gun-shy, i.e., needlessly overcautious concerning the flatness of the plate due to previous experience, the key is to do the right thing the first time (or second in this case!) and heed the next lesson learned.

5. Slow is Fast

In an effort to complete qualification testing prior to the spring graduation of some of the students on the team and to stay on schedule, the team rushed headlong into the first round of qualification testing. Although completing testing and analysis concurrently in a parallel path was a conscious decision made to minimize schedule risk, it may have had the unintended consequence of increasing the schedule risk. This is due to the fact that the team is now in a position where another failed qualification test of NPSCuL-Lite may well put delivery of a flight qualified unit by January 2010 at significant risk or possibly even out of reach. The rush to testing was not done with a conscious disregard for attention to detail; however, a lack of experience and naivety may well have contributed to the neglect of proper analysis and solicitation of professional input. Decisions were made in a rather off-the-cuff manner and details, such as flat mating surfaces, were overlooked. The biggest lesson learned from the failed qualification test was an increased awareness of the team's lack of knowledge and experience in developing flight hardware. The team learned to take time to review decisions and seek professional advice whenever a question arises. Reviews of all internally generated procedures and documentation are now standard. In the path to success, slower is usually faster.

C. THE WAY AHEAD

Much work remains to be done in order to ready NPSCuL-Lite for launch on L41 in August of 2010. The team is readying for the second qualification test. Post-test analysis will need to be completed. The material for the flight unit (or next qualification unit) has been procured, and the purchase request for manufacturing at Inter-City has been submitted and approved. Assuming the qualification test is successful, the only modification to the flight unit should be holes to accommodate the harnessing for cable routing. Along those lines, determining the cable routing and harnessing for ADAMSat will be required in the near term. The sequencer vendor, Ecliptic Enterprises, will be providing the cabling from the ABC electrical panel to the ADAMSat Sequencer Box (ASB), and Cal Poly will be providing the cabling from the ASB to the P-PODs. The NPS team has the responsibility to coordinate with both the sequencer vendor and Cal Poly in order to determine the optimum routing configuration for the cables and harnesses along the NPSCuL-Lite structure. One recommendation is to schedule a technical interchange meeting (TIM) in October to facilitate the team coming together and using an ADAMSat EDU and ABC mock-up. Ideally, both of the cable providers will have determined the physical properties of the cabling including type, gage and length prior to this TIM. There is also a substantial amount of work to be done to support integration with the launch vehicle including providing inputs to safety documentation and participation in Matchmate and Pathfinder.

After the NPSCuL-Lite flight unit is delivered in support of the first launch of ADAMSat, there are several opportunities for design and development work on future versions of NPSCuL-Lite. One difficulty faced by the NPSCuL-Lite team has been designing an integrated structure within the mass restriction of the ABC. Due to the tight schedule, the NPSCuL-Lite has been kept as simple as possible. If the NPSCuL-Lite structure can be mass optimized, it will allow more flexibility in the mass budget. Additionally, the team has also faced the challenge of the structure demonstrating a lower fundamental frequency than is preferred by the launch provider. The ICD [9, p 29] states that the SP minimum fundamental frequency must by greater than 50 Hz as cantilevered from a rigid LV interface; however, due to impacts to the launch vehicle coupled loads analysis (CLA) the launch provider has expressed interest in a stiffer integrated structure. The NPS team did some preliminary analysis on ways to modify the structure in order to increase the fundamental frequency, including the addition of brackets and struts, widening the interface of the adapter ring, etc… Any improvement that stiffens the structure should minimize the SP impact to the launch vehicle coupled loads would be of enormous benefit to future versions of the NPSCuL-Lite.

Despite the trend towards secondary payloads that are reconfigurable, launch providers insist upon knowing the exact mass properties of a secondary payload well before launch. This is due to the fact that the launch provider uses the SP mass properties to complete coupled loads analysis (CLA) which can possibly take up to several months to perform. The data provided by the CLA shows the launch provider and the primary payload what impact if any the secondary payload has on the launch vehicle and primary payload structures during launch. This has been the case with ADAMSat and ULA. ADAMSat would like to maintain some flexibility in terms of what CubeSats will eventually be manifested on ADAMSat; whereas, ULA wants specifics on the mass properties and a test verified model of the final ADAMSat four months prior to flight hardware delivery. Furthermore, delivering an ADAMSat that has different mass properties than the test verified model may place the flight of the ADAMSat in jeopardy. Due to these issues, the LSIM and the QbX office expressed interest in investigating the sensitivity of the spacecraft's modes and fundamental frequency to variations in mass properties resulting from different configurations of CubeSat loading. This could be a dual investigation involving both analysis and actual test data. The analysis could involve running simulations of the ADAMSat model varying within a given range of mass and center of gravity in order to get data on the spacecraft's frequencies. The physical test could involve varying the mass and cg of some of the P2M2s and varying their positions within the NPSCuL-Lite structure. A sine sweep on each of the three axes for each varying configuration of the integrated mass models would provide the data for analysis. If this investigation showed that the frequency of the spacecraft is relatively insensitive to the minor changes in CubeSat mass and cg, the results would provide evidence to the launch provider that maintaining flexibility in

CubeSat manifestation would not jeopardize their CLA and the launch. More significantly, this would set precedence in the launch integration process of future flights of CubeSat launchers.

The Space Test Program (STP) has repeatedly expressed interest not only in NPSCuL-Lite, but also in the original design of the NPSCuL incorporating ten 5U P-PODs and accommodating up to fifty units of CubeSat volume. Future work could include continuing structural design work as well as finite element modeling and fastener analysis. The goal in continuing development of the larger NPSCuL would be to secure funding and identify an ESPA launch opportunity.

Another opportunity for future work is in development of a sequencer for the NPSCuL-Lite. For the first flight of the NPSCuL-Lite, the sequencer is being procured from a commercial vendor. There is benefit to also developing a sequencer internally as it would give the program flexibility. LTjg Anthony Harris and Justin Jordan made progress in the initial design work and building a prototype. They also began investigating the use of COTS components in building a sequencer and did some preliminary thermal vacuum testing to determine whether those components can withstand and perform in the space environment. The efforts to date in developing a sequencer are described in the thesis, “NPS CubeSat Launcher-Lite Sequencer [28].” The new program manager should consider continuing this work as funds become available.

D. CLOSING THOUGHTS

The goal of the NPSCuL-Lite program is not only to provide education and experience to NPS students, but also to provide affordable access to space for university students, government agencies and industry. For this author, NPSCuL-Lite was a means to get valuable program management experience and be an integral part of a project that would launch hardware into space. In the end, this experience was so much more than originally expected. Most notably, the author had the privilege of collaborating with the amazing group of aerospace professionals and students that comprise the CubeSat community. These individuals are motivated, passionate and wholly committed to the development of very small satellites for the education of students and the betterment of the small satellite industry. The opportunity to learn from and build relationships with these individuals will continue to be a highlight of the author's professional career. As for the tremendous learning that took place through this experience as the NPSCuL-Lite Program Manager, the author hopes that this thesis does it justice. The author looks forward, along with the rest of the CubeSat and possibly the entire satellite community, towards the first of many launches of the NPS CubeSat Launcher!

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APPENDIX A. ASSIGNATION OF RESPONSIBILITIES

NAVAL POSTGRADUATE SCHOOL
Monterey, CA 93943-5000

Date: 06-15-2009

Memorandum

From: Principal Investigator/Program Manager
To: Research and Sponsored Programs Office (RSPO)

Subj: ASSIGNATION OF RESPONSIBILITIES BY PRINCIPAL INVESTIGATOR/ PROGRAM MANAGER (PI/PM)

Ref: (a) SPPGM-07-07: Assignation of Responsibilities by Principal Investigators/Program Managers

1. I am the Principal Investigator/Program Manager for the account identified below:

   Project Title: Student Rideshare Payload Model
   Job Order: RSPUQ

2. I hereby authorize (insert name) to initiate expenditures in support of the referenced project. My approval of the expenditures initiated under this delegation will be certified through the attestation process. The following conditions apply (check those that are appropriate):

   ______ Labor only
   ______ Equipment only
   ______ Travel only
   ______ Contracts only
   ___X___ All (Labor/Equipment/Travel/Contracts)
   ______ Limited to $: ______ for any single expenditure
   ______ Other (please specify)

3. I hereby authorize: LT Christina Hicks to initiate modifications to the Approved Expenditure Control Page. These modifications will be reviewed and approved by me prior to forwarding to the RSPO for action.

4. The authorizations noted above will remain in affect until 1) expiration date of identified account, or 2) notification from PI/PM to rescind authorization.

James H. Newman
Signature

Receipt Acknowledged:
Date: ______
RSPO ______

Copy to:
PI/PM / JH Newman
SPFA / Lori Hampton

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APPENDIX B. BUDGET FOR FY2009 QBX FUNDING

NPS Cube Sat Launcher Budget FY2009_QbX_RSPXL

	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	August	Sept	Yearly Total	Target (Set at beginning of year)	Updated Target (Feb 2009)
Labor	0.00	868.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	868.87	14355.51	868.87
Contracts/Services	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	150.00	0.00	0.00	250.00	0.00	0.00
Travel	0.00	1,738.41	1,068.40	0.00	977.15	0.00	2,274.68	0.00	0.00	0.00	2,175.14	0.00	8,233.78	3,000.00	10,000.00
Students	0.00	1738.41	1068.40	0.00	977.15	0.00	2,274.68	0.00	0.00	0.00	2,175.14	0.00	8,233.78	0.00	0.00
Equipment & Supplies	0.00	1,564.77	1,822.69	0.00	6,913.24	4,816.30	75.94	4,615.34	334.90	0.00	0.00	0.00	20,143.18	12,282.00	18,768.64
a) E&S less than $15k	0.00	1,564.77	1,822.69	0.00	6,913.24	1,966.30	0.00	0.00	0.00	0.00	0.00	0.00	12,267.00	0.00	0.00
Structure (Aluminum)	0.00	0.00	0.00	0.00	2,980.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,980.97	0.00	0.00
P-Pod Mass Models	0.00	1,564.77	1,822.69	0.00	379.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3,766.46	0.00	0.00
Sequencer Materials	0.00	0.00	0.00	0.00	361.16	1,051.30	0.00	0.00	0.00	0.00	0.00	0.00	1,412.46	0.00	0.00
Structure Fasteners	0.00	0.00	0.00	0.00	3,192.11	915.00	0.00	0.00	0.00	0.00	0.00	0.00	4,107.11	0.00	0.00
b) E&S greater than $15k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
c) Software and support	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
d) Miscellaneous	0.00	0.00	0.00	0.00	0.00	0.00	75.94	0.00	334.90		0.00	0.00	410.84	0.00	0.00
e) Manufacturing	0.00	0.00	0.00	0.00	0.00	2,850.00	0.00	0.00	0.00	0.00	0.00	0.00	2,850.00	0.00	0.00
f) Testing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,615.34	0.00	0.00	0.00	0.00	4,615.34	0.00	0.00
Vibration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,615.34	0.00	0.00	0.00	0.00	4,615.34	0.00	0.00
TVAC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indirect Cost	0.00	1,317.95	913.30	0.00	2,492.57	1,521.47	774.15	1,457.99	105.79	47.39	687.13	0.00	9,317.73	9,362.49	9,362.49
Total Expenses	0.00	5,490.00	3,804.39	0.00	10,382.96	6,337.77	3,124.77	6,073.33	440.69	47.39	2,862.27	0.00	38,813.56	39,000.00	39,000.00
Actual Cumulative Expenses	0.00	5,490.00	9,294.39	9,294.39	19,677.35	26,015.12	29,139.89	35,213.22	35,653.91	35,701.30	38,563.56	38,563.56			

FY2009 Expenses_RSPXL

Equipment/Supplies/Misc		Date	Price	Shipping	Total
	NPSCuL Mass Model Foam for Transport	11/14/2008	$63.72	$0.00	$63.72
	P-POD Mass Model Material	11/24/2008	$1,285.05	$216.00	$1,501.05
	P-POD Mass Model Fasteners	12/1/2008	$1,806.24	$16.45	$1,822.69
	NPSCuL-Lite Structure Material	2/6/2009	$2,354.11	$14.38	$2,368.49
	NPSCul-Lite Fasteners 1	2/6/2009	$1,960.00	$86.53	$2,046.53
	NPSCuL-Lite Fasteners 2	2/6/2009	$1,092.80	$52.78	$1,145.58
	P-POD Mass Model Fasteners2	2/12/2009	$356.40	$22.60	$379.00
	NPSCuL-Lite Bracket Material	2/18/2009	$537.48	$75.00	$612.48
	NPSCuL-Lite Sequencer Prototype Parts	2/26/2009	$349.02	$12.14	$361.16
	NPSCuL-Lite Structure Manufacturing	2/28/2009	$2,530.00	$0.00	$2,850.00
	NPSCuL-Lite Sequencer PCB	3/9/2009	$319.99	$8.42	$328.41
	Sequencer Mass Model Fasteners	3/9/2009	$56.50	$4.75	$61.25
	Sequencer Mass Model Material	3/9/2009	$511.64	$150.00	$661.64
	NPSCuL-Lite Fasteners 3	3/25/2009	$900.00	$15.00	$915.00
	NPSCuL-Lite Model Servo Controller	4/18/2009	$69.99	$5.95	$75.94
	Shaker Software for Testing	5/14/2009	$1,875.00	$0.00	$1,875.00
	Shaker Fuses for Testing	5/21/2009	$175.80	$17.51	$193.31
	Vibration Test Documentation	5/26/2009	$2,450.00	$0.00	$2,547.03
	NPSCuL-Lite Fastener Staking Compound	6/1/2009	$326.40	$8.50	$334.90
				Total	$20,143.18

Contracts/Services		Date	Price	Shipping	Total
	CubeSat Workshop Registration	4/29/2009	$100.00	n/a	$100.00
	Small Satellite Registration	7/23/2009	$150.00	n/a	$150.00
				Total	$250.00

Travel

Date	Destination and Purpose		Total
11/3/2008	Mtg w/ULA (Littleton, CO)	$444.24	
		$521.33	
		$394.75	$1,360.32
11/20/2008	Boeing Nano-sat Workshop (Huntington Beach, CA)	$378.09	$378.09
12/16/2008	ULA PDR (Littleton, CO)	$0.00	
		$551.90	
		$516.50	$1,068.40
2/3/2009	Government Forum on CubeSats (Kirtland AFB)	$977.15	$977.15
4/22/2009-4/25/2009	CubeSat Developers Workshop (San Luis Opisbo)	$637.34	
		$629.64	$1,266.98
4/28/2009	VAFB Technical Interchange Meeting	$403.10	
		$212.30	
		$392.30	$1,007.70
9/8/2009-9/13/2009	Small Satellite Conference (Logan, UT)	$1,225.14	$1,225.14
9/24/2009	ULA ABC CDR (Denver, CO)	$950.00	$950.00
		Total	$8,233.78

APPENDIX C. BUDGET FOR FY2009 CSEWI FUNDING

NPS Cube Sat Launcher Budget FY2009_CSEWI_RSPUQ

	May	June	July	August	September	October	Yearly Total	Target (Set June 2009)	Target (Updated Aug 2009)	Target (Updated Sep 2009)
Labor	0.00	6068.70	7070.80	7363.40	6890.40	12249.60	39,642.90	26054.60	33518.10	39642.90
Intern 1	0.00	3062.40	3062.40	3062.40	765.60	0.00	9,952.80	9952.80	9952.80	9952.80
Intern 2	0.00	2296.80	3062.40	3062.40	3062.40	6124.80	17,608.80	9952.80	14546.40	17608.80
Intern 3	0.00	709.50	946.00	473.00	0.00	0.00	2,128.50	6149.00	2128.50	2128.50
Intern 4	0.00	0.00	0.00	765.60	3062.40	6124.80	9,952.80	0.00	6890.40	9952.80
Contracts/Transfers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	450.00	0.00	0.00
Registration Fees	0.00	0.00	0.00	0.00	0.00	0.00	0			
Travel	0.00	0.00	0.00	4,078.21	0.00	0.00	4,078.21	15,000.00	9,000.00	4,078.21
Students	0.00	0.00	0.00	4,078.21	0.00	0.00	4,078.21			
Equipment & Supplies	0.00	6,100.00	8,251.00	4,951.24	0.00	636.77	19,939.01	22,155.55	21,142.05	19,939.01
a) E&S less than $15k	0.00	2,250.00	3,453.54	2,465.14	0.00	0.00	8,168.68	4,155.55		
Structure	0.00	2,250.00	972.90	1,903.50	0.00	0.00	5,126.40			
P-Pod Mass Models	0.00	0.00	2,480.64	0.00	0.00	0.00	2,480.64			
Sequencer Mass Model	0.00	0.00	0.00	561.64	0.00	0.00	561.64			
Harnessing	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
b) E&S greater than $15k	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
c) Software and support	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
d) Manufacturing	0.00	2,350.00	2,450.00	2,200.00	0.00	0.00	7,000.00	18000.00		
Flight Unit/Mass Model	0.00	2,350.00	0.00	2,200.00	0.00	0.00	4,550.00	6000.00		
P-Pod Mass Model	0.00	0.00	2,450.00	0.00	0.00	0.00	2,450.00	12000.00		
e) Testing	0.00	1,500.00	2,318.46	175.80	0.00	0.00	3,994.26			
Vibration	0.00	1,500.00	2,318.46	175.80	0.00	0.00	3,994.26			
TVAC	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
f) Miscellaneous	0.00	0.00	29.00	110.30	0.00	636.77	0.00			
Indirect Cost	0.00	5,990.65	7,542.92	8,070.20	3,392.14	6,343.96	31,339.88	31,339.89	31,339.89	31,339.88
Total Expenses	0.00	18,159.35	22,864.72	24,463.05	10,282.54	19,230.33	95,000.00	95,000.04	95,000.04	95,000.00
Actual Cumulative Expenses	0.00	18,159.35	41,024.07	65,487.13	75,769.67	95,000.00				
Uniform Burn rate	*15833.33*	*31666.67*	*47500.00*	*63333.33*	*79166.67*	*95000.00*				

FY2009 Expenses_RSPUQ

Equipment/Supplies/Misc		Date	Price	Shipping	Total
	ADaMSat Adapter Rings	6/15/2009	$2,250.00	$0.00	$2,250.00
	Shaker Conditioners/ICP Break-Out Box	6/16/2009	$1,500.00	$0.00	$1,500.00
	NPSCuL-002 Manufacturing	6/17/2009	$2,350.00	$0.00	$2,350.00
	NPSCuL-002 Fasteners	7/10/2009	$926.00	$46.90	$972.90
	P2M2v2 Material	7/10/2009	$1,808.20	$262.54	$2,070.74
	P2M2v2 Fasteners	7/23/2009	$339.00	$70.90	$409.90
	P2M2v2 Manufacturing	7/23/2009	$2,450.00	$0.00	$2,450.00
	Poster Mounting	7/24/2009	$20.00	$0.00	$20.00
	Torque Bits	7/28/2009	$4.50	$4.50	$9.00
	Shaker Sensors	7/28/2009	$2,283.46	$35.00	$2,318.46
	Sequencer v2 Material	8/18/2009	$511.64	$50.00	$561.64
	Thread Lock AE-10	8/19/2009	$75.30	$35.00	$110.30
	NPSCuL-003 Manufacturing	8/19/2009	$2,200.00	$0.00	$2,200.00
	NPSCuL-003 Material	8/31/2009	$1,794.19		$1,794.19
	NPSCuL-003 Brackets	8/31/2009	$109.31		$109.31
	Shaker Fuses	8/31/2009	$175.80		$175.80
				Total	$19,302.24

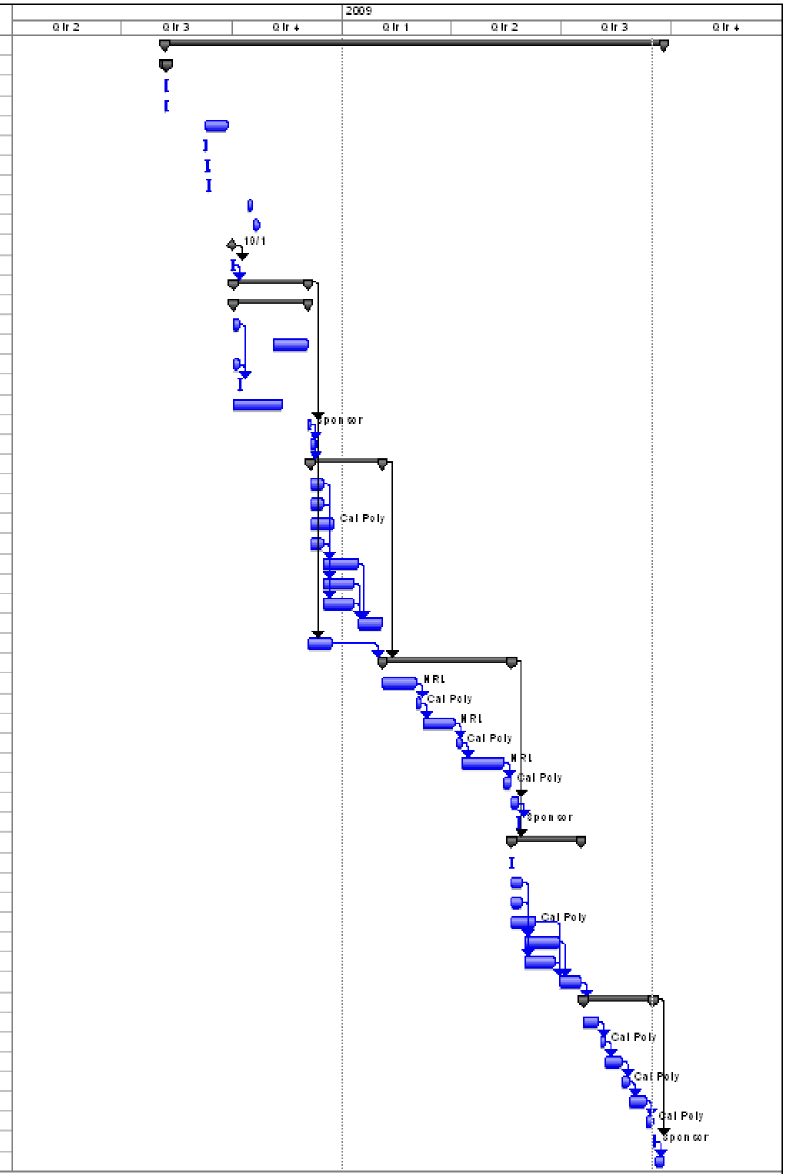
Contracts/Services	Date	Price	Shipping	Total
			Total	$0.00

Travel

Date	Destination and Purpose		Total
	Small Satellite Conference	$1,032.24	$1,032.24
8/24-8/25/2009	ULA ABC CDR (Denver, CO)	$497.75	
		$779.70	
		$885.22	
		$883.30	$3,045.97
		Total	$4,078.21

APPENDIX D. NPSCUL-LITE INITIAL PROGRAM SCHEDULE

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	NPSCuL Lite	298 days	Wed 8/6/08	Thu 9/24/09		
2	Proposal	2 days	Wed 8/6/08	Thu 8/7/08		
3	Complete Initial Budget	2 days	Wed 8/6/08	Thu 8/7/08		
4	Complete Initial Schedule	2 days	Wed 8/6/08	Thu 8/7/08		
5	Learn IDEAS	14 days	Tue 9/9/08	Fri 9/26/08		
6	Prep for DoD SERB practice	2 days	Mon 9/8/08	Tue 9/9/08		
7	DoD SERB practice via VTC	1 day	Wed 9/10/08	Wed 9/10/08		
8	DoD SERB Travel Arrangements	1 day	Thu 9/11/08	Thu 9/11/08		
9	Prep for DoD SERB	4 days	Tue 10/14/08	Fri 10/17/08		
10	DoD SERB Travel	4 days	Sun 10/19/08	Wed 10/22/08		
11	Receipt of Funding	0 days	Wed 10/1/08	Wed 10/1/08		
12	Preliminary Design Review	1 day	Wed 10/1/08	Wed 10/1/08	11	
13	System Design	45 days	Thu 10/2/08	Tue 12/2/08	12	
14	Structural Design	45 days	Thu 10/2/08	Tue 12/2/08		
15	Complete Drawings & Details	3 days	Thu 10/2/08	Mon 10/6/08		
16	Structural Modeling	21 days	Tue 11/4/08	Tue 12/2/08		
17	Develop Mass Budget	3 days	Thu 10/2/08	Mon 10/6/08		
18	Collaborate with Machinist	1 day	Tue 10/7/08	Tue 10/7/08	15, 17	
19	Sequencer Design	30 days	Thu 10/2/08	Tue 11/11/08		
20	Critical Design Review (CDR)	2 days	Wed 12/3/08	Thu 12/4/08	13	Sponsor
21	Review/Revise Budget & Schedule	3 days	Fri 12/5/08	Tue 12/9/08	20	
22	Build Qualification Unit	42 days	Fri 12/5/08	Mon 2/2/09	20	
23	Acquire materials for Structure	7 days	Fri 12/5/08	Mon 12/15/08		
24	Acquire materials for Sequencer	7 days	Fri 12/5/08	Mon 12/15/08		
25	Acquire P-Pods	14 days	Fri 12/5/08	Wed 12/24/08		Cal Poly
26	Acquire materials for Mass Models	7 days	Fri 12/5/08	Mon 12/15/08		
27	Build Structure	21 days	Tue 12/16/08	Tue 1/13/09	23	
28	Build Sequencer	19 days	Tue 12/16/08	Fri 1/9/09	24	
29	Build Mass Models	19 days	Tue 12/16/08	Fri 1/9/09	26	
30	Integrate Qualification Unit	14 days	Wed 1/14/09	Mon 2/2/09	27,28,29	
31	Develop Test Documents	14 days	Wed 12/3/08	Mon 12/22/08	13	
32	Test Qualification Unit	77 days	Tue 2/3/09	Wed 5/20/09	22,31	
33	Vibration	20 days	Tue 2/3/09	Mon 3/2/09		NRL
34	Functional Test	4 days	Tue 3/3/09	Fri 3/6/09	33	Cal Poly
35	Shock	20 days	Mon 3/9/09	Fri 4/3/09	34	NRL
36	Functional Test	4 days	Mon 4/6/09	Thu 4/9/09	35	Cal Poly
37	ThermoVac	25 days	Fri 4/10/09	Thu 5/14/09	36	NRL
38	Functional Test	4 days	Fri 5/15/09	Wed 5/20/09	37	Cal Poly
39	Post Qual Test Review Prep	4 days	Thu 5/21/09	Tue 5/26/09	32	
40	Post Qual Test Review	1 day	Wed 5/27/09	Wed 5/27/09	39	Sponsor
41	Build Flight Structure	42 days	Thu 5/21/09	Fri 7/17/09	32	
42	Collaborate with Machinist	1 day	Thu 5/21/09	Thu 5/21/09		
43	Acquire materials for Flight Structure	7 days	Thu 5/21/09	Fri 5/29/09		
44	Acquire materials for Sequencer	7 days	Thu 5/21/09	Fri 5/29/09		
45	Acquire P-Pods for Flight Structure	14 days	Thu 5/21/09	Tue 6/9/09		Cal Poly
46	Build Flight Structure	21 days	Mon 6/1/09	Mon 6/29/09	43	
47	Build Sequencer	19 days	Mon 6/1/09	Thu 6/25/09	44	
48	Integrate Flight Unit	14 days	Tue 6/30/09	Fri 7/17/09	46,47,45	
49	Flight Unit Acceptance Testing	42 days	Mon 7/20/09	Tue 9/15/09	48	
50	Vibration	10 days	Mon 7/20/09	Fri 7/31/09		
51	Functional Test	4 days	Mon 8/3/09	Thu 8/6/09	50	Cal Poly
52	Shock	10 days	Fri 8/7/09	Thu 8/20/09	51	
53	Functional Test	4 days	Fri 8/21/09	Wed 8/26/09	52	Cal Poly
54	ThermoVac	10 days	Thu 8/27/09	Wed 9/9/09	53	
55	Functional Test	4 days	Thu 9/10/09	Tue 9/15/09	54	Cal Poly
56	Flight Readiness Review	2 days	Wed 9/16/09	Thu 9/17/09	49	Sponsor
57	NPSCuL Delivery for Integration	5 days	Fri 9/18/09	Thu 9/24/09	56	



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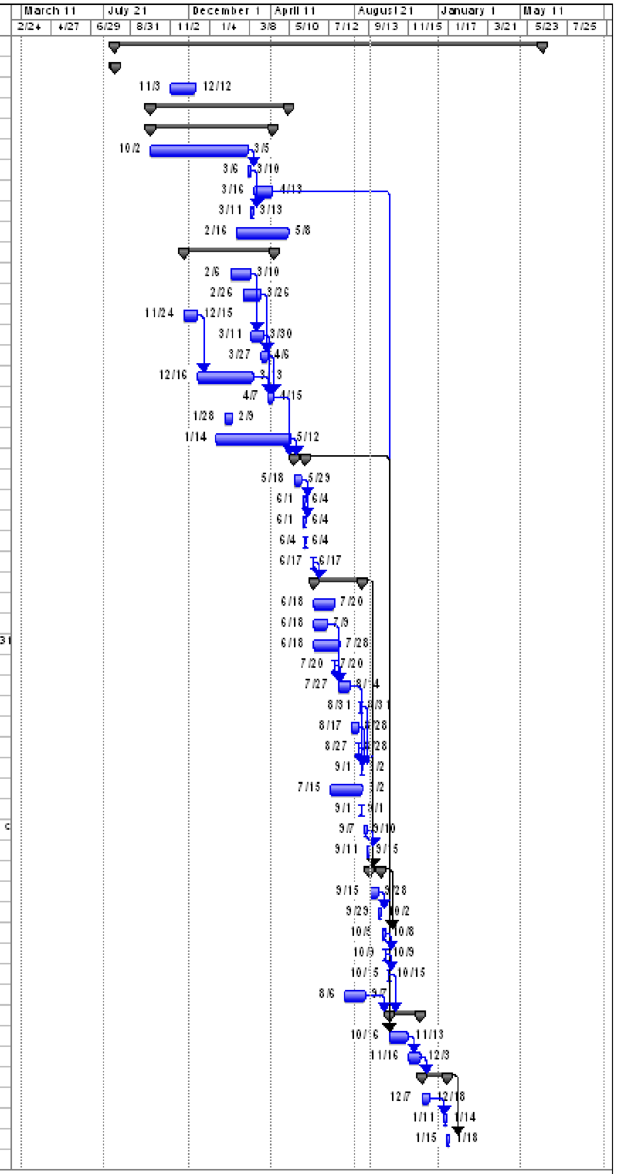
APPENDIX E. NPSCUL-LITE UPDATED PROGRAM SCHEDULE

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	NPSCuL Lite	486 days	Wed 8/6/08	Tue 6/15/10		
2	Proposal	2 days	Wed 8/6/08	Thu 8/7/08		
5	Learn IDEAS	30 days	Mon 11/3/08	Fri 12/12/08		
6	System Design	158 days	Thu 10/2/08	Fri 5/8/09		
7	Structural Design	139 days	Thu 10/2/08	Mon 4/13/09		
8	Design	112 days	Thu 10/2/08	Thu 3/5/09		
9	Complete Drawings & Details	3 days	Fri 3/6/09	Tue 3/10/09	8	
10	Structural Modeling	21 days	Mon 3/16/09	Mon 4/13/09		
11	Develop Mass Budget	3 days	Wed 3/11/09	Fri 3/13/09	9	Ongoing
12	Sequencer Design	60 days	Mon 2/16/09	Fri 5/8/09		
13	Build Qualification Unit(NPSCuL 001)	103 days	Mon 11/24/08	Wed 4/15/09		
14	Acquire materials for Structure	23 days	Fri 2/6/09	Tue 3/10/09		Ordered 1/14
15	Acquire materials for Sequencer MM	21 days	Thu 2/26/09	Thu 3/26/09		Ordered 3/9
16	Acquire materials for P-POD MM	16 days	Mon 11/24/08	Mon 12/15/08		
17	Build Structure	14 days	Wed 3/11/09	Mon 3/30/09	14	Ordered 2/28. Commenced 3/11
18	Build Sequencer Mass Model	7 days	Fri 3/27/09	Mon 4/6/09	15	
19	Build P-POD Mass Models	64 days	Tue 12/16/08	Fri 3/13/09	16	Actual metal cut 2/1/09
20	Integrate Qualification Unit	7 days	Tue 4/7/09	Wed 4/15/09	17,18,	
21	Design/Build Shaker Plate Assembly	9 days	Wed 1/28/09	Mon 2/9/09		
22	Develop Test Documents	85 days	Wed 1/14/09	Tue 5/12/09		
23	Test Qualification Unit	14 days	Mon 5/18/09	Thu 6/4/09	20,22	
24	Vibration	10 days	Mon 5/18/09	Fri 5/29/09		
25	Functional Test	4 days	Mon 6/1/09	Thu 6/4/09	24	Cal Poly
26	Post Qual Test Review Prep	4 days	Mon 6/1/09	Thu 6/4/09	24	
27	Post Qual Test Review	1 day	Thu 6/4/09	Thu 6/4/09		
28	Updated NPSCuL/P2M2 Design Review	1 day	Wed 6/17/09	Wed 6/17/09		
29	Build Qualification Unit(NPSCuL 002)	55 days	Thu 6/18/09	Wed 9/2/09	28	
30	Acquire materials for Structure	23 days	Thu 6/18/09	Mon 7/20/09		Ordered 6/21
31	Acquire materials for P-POD MM	16 days	Thu 6/18/09	Thu 7/9/09		Ordered 7/10. Received 7/20
32	Manufacture Structure	29 days	Thu 6/18/09	Tue 7/28/09		Ordered 6/18. Commenced 6/22. Received 7/31
33	P2M2 Follow-on Design Review	1 day	Mon 7/20/09	Mon 7/20/09		
34	Build P-POD Mass Models	15 days	Mon 7/27/09	Fri 8/14/09	33,31	Ordered 7/24. Received 8/7.
35	Acquire P-PODs from Cal-Poly	1 day	Mon 8/31/09	Mon 8/31/09		
36	Sequencer Mass Model Manufacture	10 days	Mon 8/17/09	Fri 8/28/09		
37	Assemble Structure	2 days	Thu 8/27/09	Fri 8/28/09		Delayed due to incorrect fastener order
38	Integrate Qualification Unit	2 days	Tue 9/1/09	Wed 9/2/09	37,34,	
39	Update Test Plan	36 days	Wed 7/15/09	Wed 9/2/09		Review on 9/3/09
40	Tap Test	1 day	Tue 9/1/09	Tue 9/1/09		CSA Engineering
41	Test Shaker	4 days	Mon 9/7/09	Thu 9/10/09		Dave Rigmalden/Dan Sakoda; delayed due to c
42	Test P2M2v2	3 days	Fri 9/11/09	Tue 9/15/09	41	
43	Test Qualification Unit	14 days	Tue 9/15/09	Fri 10/2/09	29	
44	Vibration	10 days	Tue 9/15/09	Mon 9/28/09		
45	Functional Test	4 days	Tue 9/29/09	Fri 10/2/09	44	Cal Poly
46	Post Qual Test Review Prep	4 days	Mon 10/5/09	Thu 10/8/09	43	
47	Post Qual Test Review	1 day	Fri 10/9/09	Fri 10/9/09	46	
48	NPSCuL Design Review	1 day	Thu 10/15/09	Thu 10/15/09	47	
49	Acquire materials for Flight structure	23 days	Thu 8/6/09	Mon 9/7/09		
50	Build Flight Structure	35 days	Fri 10/16/09	Thu 12/3/09	43,48	
51	Build Flight Structure	21 days	Fri 10/16/09	Fri 11/13/09	10,23	
52	Integrate Flight Unit	14 days	Mon 11/16/09	Thu 12/3/09	51	
53	Flight Unit Acceptance Testing	29 days	Mon 12/7/09	Thu 1/14/10	52	
54	Vibration	10 days	Mon 12/7/09	Fri 12/18/09		
55	Functional Test	4 days	Mon 1/11/10	Thu 1/14/10	54	Cal Poly
56	Flight Readiness Review	2 days	Fri 1/15/10	Mon 1/18/10	53	Sponsor
57						



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